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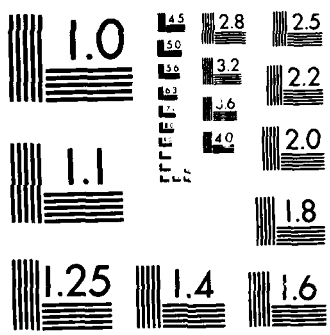

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Massachusetts
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Knowledge-Based
Integrated Information
Systems Engineering
(KBIISE) Project

Volume 6

Strategic, Organizational, and Standardization Aspects of Integrated Information Systems

(2)

Amar Gupta
Stuart Madnick
SERIES EDITORS

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER KBIISE-6	2. GOVT ACCESSION NO. [illegible] 85	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Strategic, Organizational, and Standardization Aspects of Integrated Information Systems		5. TYPE OF REPORT & PERIOD COVERED Part of Final Report- Sept 86 to Jan 88
		6. PERFORMING ORG. REPORT NUMBER KBIISE-5
7. AUTHOR(s) Amar Gupta and Stuart Madnick (editors)		8. CONTRACT OR GRANT NUMBER(s) DTRS57-85-C-00083
9. PERFORMING ORGANIZATION NAME AND ADDRESS Massachusetts Institute of Technology Cambridge, MA 02139		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Transportation Systems Center Broadway Street, Cambridge, MA 02142 (w/USAF)		12. REPORT DATE December, 1987
		13. NUMBER OF PAGES 256
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Transportation Systems Center Broadway Street Cambridge, MA 02142		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This volume is one of eight volumes prepared by MIT for the Department of Transportation and Department of Defense (U.S. Air Force).

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Integration, knowledge, databases, systems engineering, methodologies, information modeling, heterogeneous database systems.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This volume highlights key strategic and organizational issues involved in integrating heterogeneous information systems. It is divided into four parts. The first part, "Towards a CIS Model for Strategic Applications" explores the nature of strategic goals underlying composite information systems (CIS) and ways to increase the likelihood of success. These aspects are analyzed using an example in which the relationship between the constituents is loosely-coupled and inter-dependent.

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The second part, "Interorganizational Information Systems via Information Technology: A Network Perspective" deals with the evolution of organizational theory and the importance of inter-organizational information networks. By effective establishment and use of these networks, participating organizations can realize competitive advantages in the marketplace.

The third part, "The Use of Standard Data Definitions in Composite Information Systems," describes the problems involved in establishing common standards. Between the two extremes of laying organization-wide standards and permitting all participants to establish their guidelines, the option of "Focused Standards" offers distinct advantages.

The fourth part describes a methodology for the development of standards for data exchange in an integrated environment. Based on a careful study of the development of the Product Data Exchange Standard (PDES), the part contains recommendations for the future development of PDES as well as for the development of data exchange standards in general.

STRATEGIC, ORGANIZATIONAL, AND STANDARDIZATION ASPECTS OF INTEGRATED INFORMATION SYSTEMS

Amar Gupta
Stuart Madnick

Series Editors

Knowledge-Based Integrated Information Systems Engineering (KBIISE) Report: Volume 6

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Massachusetts Institute of Technology

STRATEGIC, ORGANIZATIONAL, AND STANDARDIZATION ASPECTS OF INTEGRATED INFORMATION SYSTEMS

About This Volume

This volume highlights key strategic and organizational issues involved in integrating heterogeneous information systems. It is divided into four parts. The first part, "*Towards a CIS Model for Strategic Applications*," explores the nature of strategic goals underlying composite information systems (CIS) and ways to increase the likelihood of success. These aspects are analyzed using an example in which the relationship between the constituents is loosely-coupled and inter-dependent.

The second part, "*Interorganizational Information Systems Via Information Technology: A Network Perspective*," deals with the evolution of organizational theory and the importance of inter-organizational information networks. By effective establishment and use of these networks, participating organizations can realize competitive advantages in the marketplace.

The third part, "*The Use of Standard Data Definitions in Composite Information Systems*," describes the problems involved in establishing common standards. Between the two extremes of laying organization-wide standard and permitting all participants to establish their guidelines, the option of 'Focused Standards' offers distinct advantages.

The fourth part describes a methodology for the development of standards for data exchange in an integrated environment. Based on a careful study of the development of the Product Data Exchange Standard (PDES), this part contains recommendations for the future development of PDES as well as for the development of data exchange standards in general. Keywords: Knowledge Based Information System Engineering (KBIISE).

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Knowledge-Based Integrated Information System Engineering Project: Volume 6

Amar Gupta and Stuart E. Madnick, Editors

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SERIES EDITORS' NOTE

This book is one of eight volumes published by MIT as part of the Knowledge-Based Integrated Information Systems Engineering Project (KBIISE). In order to appreciate the papers in this book, it is necessary to be aware about the theme of the KBIISE project, its major objectives, and the different documents that summarize the research accomplishments to date.

Goal

The primary goal of the KBIISE project is to integrate islands of disparate information systems that characterize virtually all large organizations. The number and the size of these islands has grown over years and decades as organizations have invested in an increasing number of computer systems to support their growing reliance on computerized data. This has made the problem of integration more pronounced, complex, and challenging.

The need for multiple systems in large organizations is dictated by a combination of technical reasons (such as the desired level of processing power and the amount of storage space), organizational reasons (such as each department obtaining its own computer based on its function), and strategic reasons (such as the level of reliability, connectivity, and backup capabilities). Further, underlying trends in the information technology area have led to a situation where most organizations now depend on a portfolio of information processing machines, ranging from mainframes to minicomputers and from general purpose workstations to sophisticated CAD/CAM systems, to support their computational requirements. The tremendous diversity and the large size of the different systems make it difficult to integrate these systems.

Key Participants

The above problem is becoming increasingly evident in all large government agencies and in large development programs. In the fall of 1986, the U.S. Air Force (USAF) and the Transportation Systems Center (TSC) of the U.S. Department of Transportation approached M.I.T. to conduct and to coordinate research activity in this area in order "to develop the framework for a comprehensive methodology for large scale distributed, heterogeneous information systems which will provide: (i) the necessary structure and standards for an evolving top down global framework; (ii) simultaneous bottom up systems development; and (iii) migratory paths for existing systems."

Both USAF and TSC provided sustained assistance to members of our research team. In addition, Citibank and IBM provided some funds for research in very specific areas. One advantage of our corporate links was the opportunity to analyze and to generate case studies of actual decentralized organizational environments.

The research sponsors and MIT agreed that in order to deal with the heterogenity issue in a meaningful way, it was important that a critical mass of influential individuals participate in the development of solutions. Only through widespread discussion and acceptance of a proposed strategy would it become feasible to deal with the major problems. For these reasons, a Technical Advisory Panel (TAP) was constituted. Nominees to the TAP included experts from academic and research organizations, government agencies, computer companies, and other corporations. In addition, several subcontractors, the primary one being Texas A&M University, provided assistance in specific areas.

Technical Outputs

The scope of the work included (i) technical issues; (ii) organizational issues; and (iii) strategic issues. On the basis of exploratory research efforts in all these areas, 24 technical reports were prepared. Eighteen of these reports were generated by MIT research personnel, and their respective areas of investigation are summarized in the figure on the opposite page.

The five technical reports, not represented in the figure, are as follows:

#1. Summary.

#2. Record of discussions held at the first meeting of the Technical Advisory Panel (TAP) on February 17, 1987.

#3. Consolidated report submitted by Texas A&M University.

#21. Annotated Bibliography.

#23. Record of discussions held at the second meeting of the Technical Advisory Panel (TAP) on May 21 and 22, 1987.

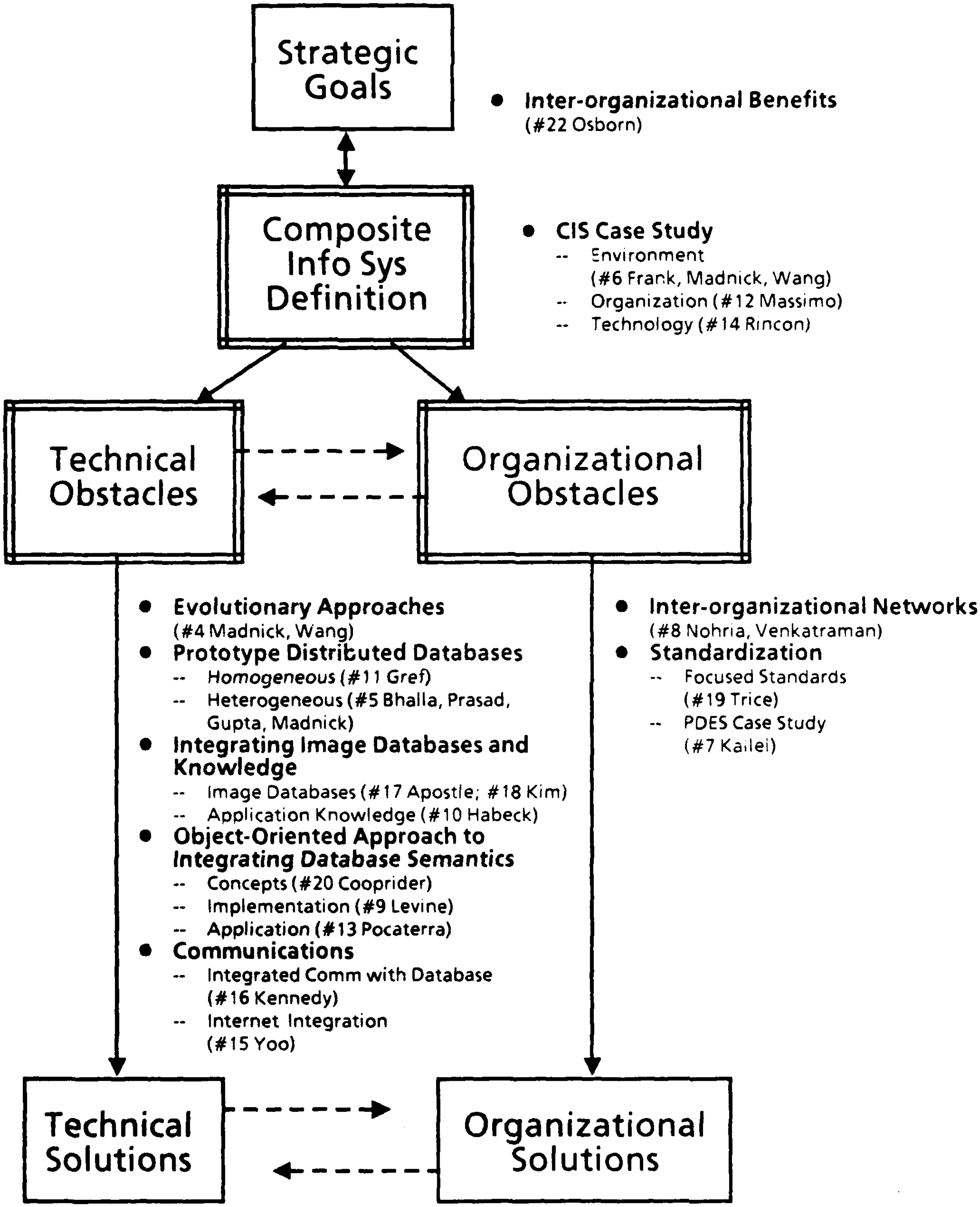
#24 Contributions received from members of the TAP highlighting their views on various aspects of the problem.

All the 24 technical reports have been edited and reorganized as an eight-volume set. The titles of the different volumes are as under:

1. KNOWLEDGE-BASED INTEGRATED INFORMATION SYSTEMS ENGINEERING–HIGHLIGHTS AND BIBLIOGRAPHY
2. KNOWLEDGE-BASED INTEGRATED INFORMATION SYSTEMS DEVELOPMENT METHODOLOGIES PLAN
3. INTEGRATING DISTRIBUTED HOMOGENEOUS AND HETEROGENEOUS DATABASES PROTOTYPES
4. OBJECT-ORIENTED APPROACH TO INTEGRATING DATABASE SEMANTICS
5. INTEGRATING IMAGES, APPLICATIONS, AND COMMUNICATIONS NETWORKS
6. STRATEGIC, ORGANIZATIONAL, AND STANDARDIZATION ASPECTS OF INTEGRATED INFORMATION SYSTEMS
7. INTEGRATING INFORMATION SYSTEMS IN A MAJOR DECENTRALIZED INTERNATIONAL ORGANIZATION
8. TECHNICAL OPINIONS REGARDING KNOWLEDGE-BASED INTEGRATED INFORMATION SYSTEMS ENGINEERING

Volume 2 contains the report submitted by Texas A&M and Volume 8 highlights the views of members of the TAP. Activities described in the other 6 volumes have been conducted at MIT.

EXPLORATORY RESEARCH EFFORTS



Acknowledgments

Funds for this project have been provided by U.S. Air Force, U.S. Department of Transportation (Contract Number DTRS57-85-C-00083), IBM, and Citibank. We thank all these organizations and their representatives for their support. In particular, we are indebted to Major Paul Condit of U.S. Air Force for his initiative in sponsoring this project, to Dr. Frank Hassler, Bud Giangrande, and Bob Berk of the Transportation Systems Center (TSC) for their support and assistance, to Professor Joseph Sussman, Director, Center for Transportation Studies (CTS) at MIT for his help and encouragement, and to all the individuals whose results have been published in this book.

We would welcome receiving feedback from readers of this book.

Amar Gupta and S.E. Madnick
Massachusetts Institute of Technology
Cambridge, Massachusetts.

TOWARDS A CIS MODEL FOR STRATEGIC APPLICATIONS

CHARLEY OSBORN

This research effort explores the nature of strategic goals underlying composite information systems (CIS) and ways to increase the likelihood of success. It studies a major regional hospital and its relationships with its physicians as part of an actual case study for providing physicians and staff convenient interface to disparate hospital departments. This situation is a particularly appropriate CIS example since the relationship is clearly loosely-coupled and inter-dependent (i.e., the physicians can affiliate with any hospital they want but must, in most cases, affiliate with some hospital).

Using Competitive Forces (Porter, 1985) and Critical Success Factors (Rockart, 1982) analysis techniques, several strategic concerns for the hospital were identified:

1. Compression of margins due to 3rd-party payment systems are making volume and occupancy levels critical.
2. Physician affiliation is critical since over 60% of patients are guided to a specific hospital by physician referral.

Two strategic issues affecting physicians have been noted:

3. Physician office overhead costs have been rising (estimated to be over 60% of revenues by the end of 1987)
4. Referrals, by other physicians and hospitals, are important source of patients. (Side note: the hospital provides various community services where it refers patients to physicians)

Looking toward the future, the hospital saw two additional important interdependencies:

5. Pressure from 3rd-party payers for better productivity measures are going to require more information sharing between hospital and physician.
6. Must not alienate or pressure physicians to provide sensitive information. Peer pressure and evolution best way to alter physician behavior.

Although the specific strategic issues listed above are particular to this case, they are very representative of most CIS situations. In order for these issues to be resolved cooperation is necessary and can be accomplished in three ways:

1. <u>Bi-directional benefits and incentives</u> (i.e., "what's in it for me?") Different advantages accrue to parties individually yet bi-directional means that there are advantages received by both parties. For example, electronic referrals by hospital to doctor increase doctor revenue and simplify office procedures while referrals by doctor to hospital increase hospital volume and help to even out scheduling loads.
2. <u>Co-operative payoffs.</u> Same benefits to all participants with aggregate benefit higher than costs. For example, electronic transmission of laboratory test requests and results benefits both the lab and physician, saving considerable staff time and minimizing delay for both.
3. <u>Asymmetrical control.</u> By agreement, both participants are not equal. For example, since the physicians have neither the time nor interest to set up the network (but do reap the benefits noted above), they are willing to allow the hospital to control it as long as it does not constrain their usage. The hospital, on the other hand, is willing to take on this task since it provides an evolutionary basis for extracting information that will be needed in the future.

As an additional finding, the use of flexible low-cost prototyping technology was found to be very valuable since it allowed the hospital to start small, yet grow and evolve from experience and respond to needs rapidly.

1. Introduction:

This paper 1) suggests further definition for Madnick and Wang's Composite Information System (CIS) process model[1] and 2) describes three generalized elements important when composite information systems span organizational boundaries. The cooperative and incentive-based aspects of boundary-crossing CIS receive particular attention. The experience of Abbott Northwestern Hospital, a large Minneapolis tertiary care facility, illustrates these concepts.

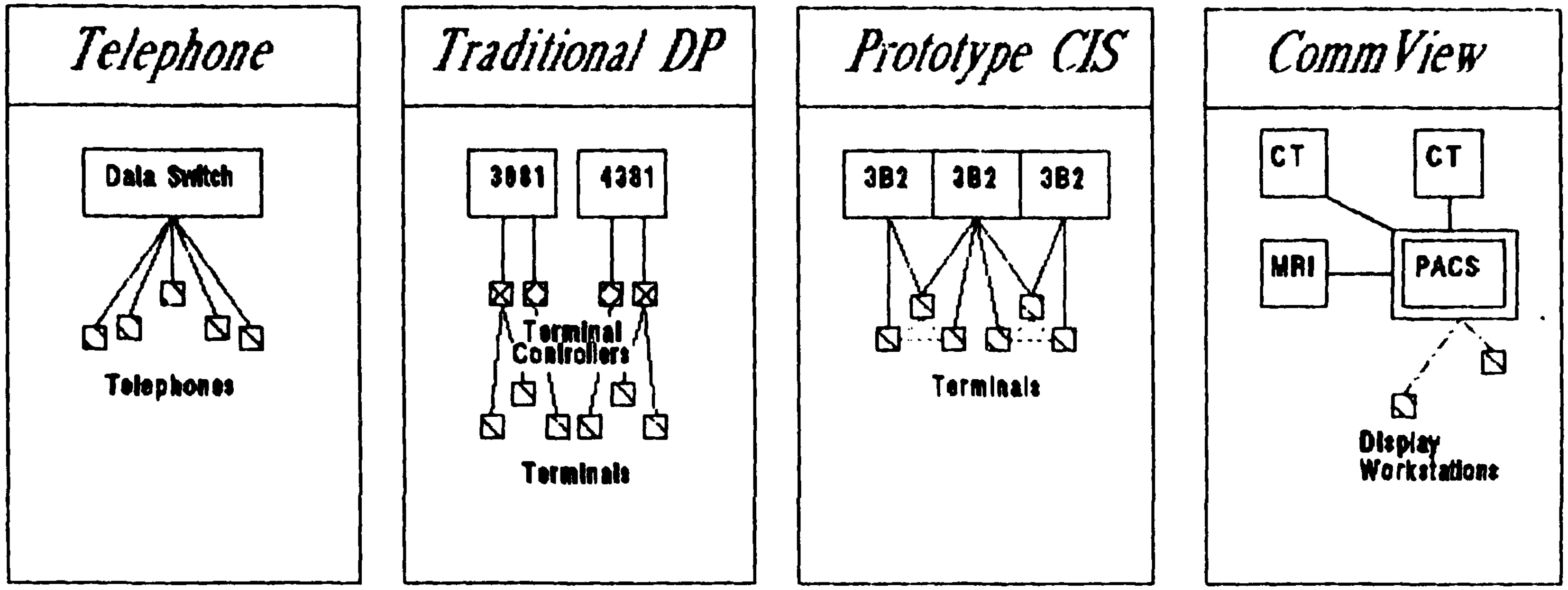
Part B (which can be read independently) describes the hospital's markets, organization, strategies, and four key information networks in some detail. Figure 1 shows the networks in schematic form. Abbott controls:

1. an in-house telephone network;
2. a traditional IBM mainframe-based data processing system;
3. an experimental Unix-based Professional Information Network (PIN - listed in Figure 1 as a prototype Composite Information System, or CIS); and
4. an experimental Picture Archiving and Communications System (PACS) for capturing Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) output as well as digitizing x-ray films. The PACS is known within Abbott by its AT&T product name - CommView.

This paper will focus on how Abbott's managers use and plan to use these networks - particularly PIN - to

[1]From Madnick, S. E. and Wang, Y. R., "Gaining Strategic Advantage Through Composite Information Systems", unpublished working paper, Sloan School of Management 1987, p. 6 and fig. 4.

Abbott Northwestern: Four Networks



Major Applications	Answering Service	PACE, Accounting	Prof. Info. N/W (PIN)	PACS (Images)
Connects	H&H, H&P, P&P	W/in H	H & H, H & P, P & P	W/in H, w/ one regional H
Format	Voice	Text, Binary	Text (binary possible)	Image only
Software	AT&T Custom	IBM & In-house	Unix, Informix	AT&T Custom
Personnel Investment	6	86	2	Beta Test (3; 125)

figure 1

strengthen the hospital's strategic position. Abbott Northwestern has 774 beds and is the largest hospital in Minneapolis. With over 40% of the area's licensed beds, a 71% bed utilization rate compared with its closest competitor's 68%, and more than 1,000 practicing physicians, Abbott is the flagship facility of one of Minneapolis' four dominant multi-hospital systems. Figure 2 summarizes Abbott's size, services, and competitive position. Beginning with the development of an in-house answering service in the early 1980s which offered Abbott doctors access to the Abbott telephone network at competitive rates, Abbott's management has been searching for ways to build inter-organizational bridges between the hospital and attending physicians' practices. The PIN network represents the latest attempt to do so.

There are several reasons why Abbott's managers believe that strengthening loyalties between physicians and the hospital assume strategic importance. Regional healthcare market trends are intensifying the importance of patient volume and market share. The negotiated pricing encouraged by HMOs (in Minneapolis HMOs represent 50% of the patient population compared with 10% nation-wide) has combined with rising operating costs to put hospital revenues and profits under serious pressure. Other hospital chains are located nearer to affluent portions of the city than Abbott - an advantage when targeting low-risk HMO patients. New competitors are appearing. Free-standing clinics siphon

ABBOTT NORTHWESTERN HOSPITAL

Minneapolis, Minnesota

---

774 Beds

1033 Practicing Physicians

4000 employees

25 fully equipped operating suites

10 major specialty clinics

Over $225 million annual revenue

Top 5% of US healthcare delivery systems in size and reputation

Tertiary care, nationally known in cardiology

One of 4% of American hospitals to support a Radiology residency program

Of 4 Dominant Multihospital Systems (41% of 10,000 lic. beds)

3rd in # of beds
2nd in revenues
1st in inpatient census

71% Utilization vs. 68% vs. 47% avg.

figure 2

off high-revenue low-risk procedures (such as radiology. Primary-care hospitals are attempting to develop their own specialties. Smaller hospitals are consolidating with large multi-hospital organizations as financial conditions worsen. Figure 3 summarizes many of these trends using the market framework introduced by Michael Porter[2].

Abbott's managers have isolated the critical aspects related to each of these competitive threats and have developed strategies for countering them. Figure 4 shows the most important parts of this response. Abbott intends to bolster market share and patient volume by building its reputation among physicians and its image as a specialty health-care institution among the public. Patient referrals are a key method for building volume. Because physicians are responsible for more than half of referrals, the physician relationship becomes a key strategic factor in maintaining the hospital's financial health. It is in Abbott's strategic interest to bind its physicians as tightly to the hospital as possible. Services provided by the hospital which save the physician time or which reduce the overhead associated with the physician's practice thus assume strategic importance. As time passes, Abbott's management expects that the hospital will have to ask physicians for increasingly proprietary data in assembling cost data for pricing negotiations. If the hospital can

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[2]For Porter's framework see Porter, Michael E., Competitive Strategy: Techniques for Analyzing Industries and Competitors. New York: Free Press 1980, p. 4.

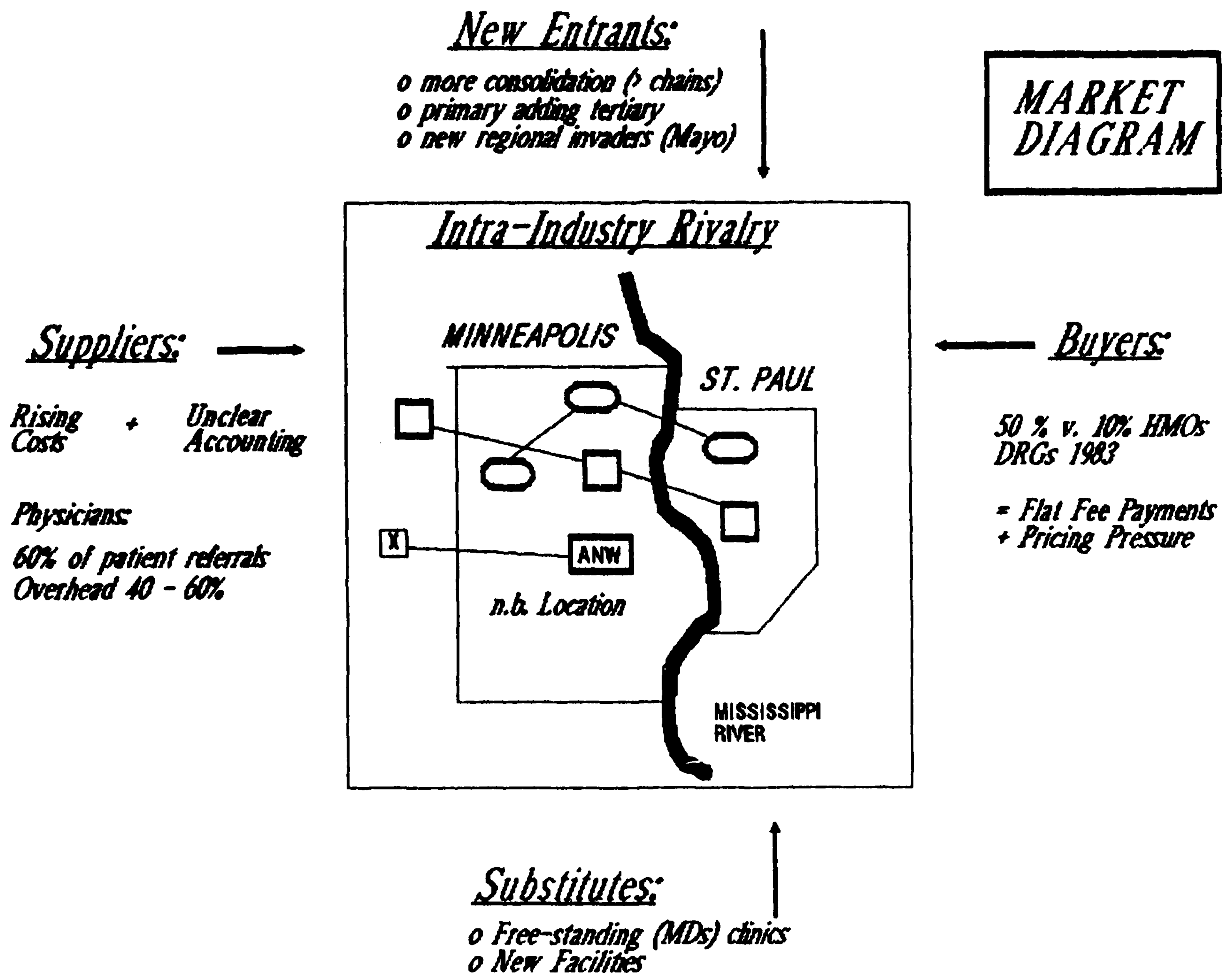
MARKET DIAGRAM
New Entrants:
o more consolidation (> chains)
o primary adding tertiary
o new regional invaders (Mayo)
Intra-Industry Rivalry
MINNEAPOLIS
ST. PAUL
ANW
X
n.b. Location
MISSISSIPPI RIVER
Suppliers:
Rising Costs + Unclear Accounting
Physicians:
60% of patient referrals
Overhead 40 - 60%
Buyers:
50 % v. 10% HMOs
DRGs 1983
= Flat Fee Payments
+ Pricing Pressure
Substitutes:
o Free-standing (MDs) clinics
o New Facilities

figure 3

Abbott Northwestern: Key Strategic Factors

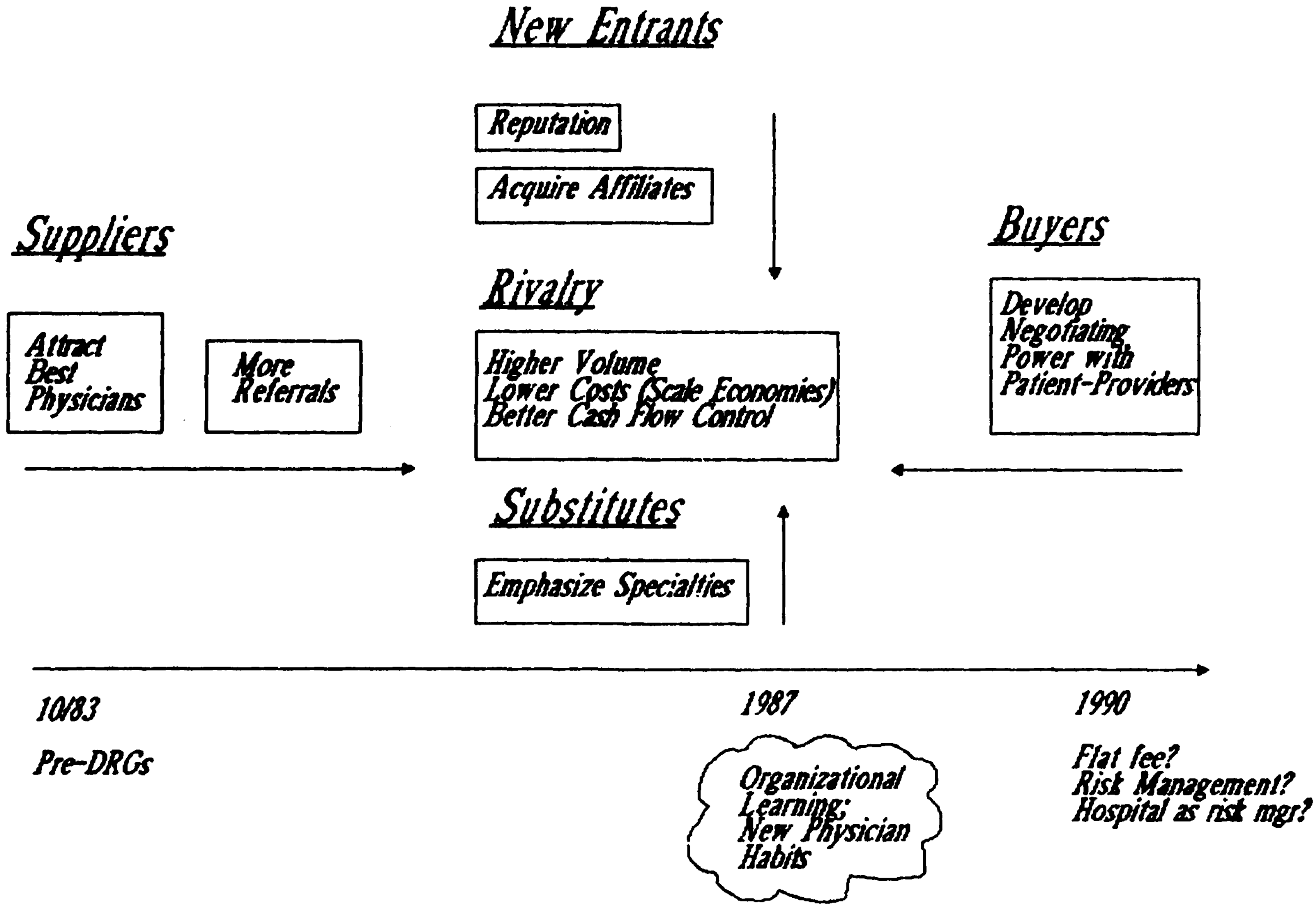

figure 4

provide important services to its physicians over an electronic network while simultaneously acclimating its doctors to the convenience of electronic data transmittal, the Abbott will have encouraged trends in organizational learning which will grow in competitive importance over the next decade. PIN represents an attempt to accomplish these goals.

2. The PIN Network as CIS:

On the surface PIN resembles a simple Unix mail network running on three AT&T 3B2 computers. Abbott managers, however, are extending the system's use (although not necessarily its current form) into areas that are closer to a strategic CIS than to a simple mail network. PIN provides an example which is technically simple but which uncovers many of the important analytical and organizational aspects of a CIS environment. Figure 5 describes major PIN features. The system links locations within the hospital, connects the hospital to physicians' offices, and connects physicians to physicians: it is primarily inter-organizational in scope. The cost to connect to the network is at most $1,300 and PIN's central harware costs less than $100,000 - which compares favorably with the 80 man-years of development time which Abbott's data processing department estimated for a customized mainframe-based system. The network provides eight core services: 1) electronic mail,

P I N

PROFESSIONAL INFORMATION NETWORK

SCOPE

Hospital to Hospital
Hospital to Physician
Physician to Physician
Hospital to HMO

Pilot runs 100+ terminals

Cost per hookup $1300
(compare with 40 people 2 years)

SERVICES

Electronic Mail
Referrals
Lab requests/results
Pharmacy
Pre-admission
Operating Room (OR) scheduling
Consultation requests
Library

To be added:

Electronic billing signatures
Outside databases direct

CONFIGURATION

3 x AT&T 3B2
Unix mail
Shell interface programs
1 programmer
...afternoon updates, additions
Informix
< $90,000
PCs and modems owned by many doctors.

figure 5

2) referrals, 3) lab status requests, 4) pharmacy queries, 5) pre-admission forms, 6) operating room scheduling, 7) consultation requests, and 8) library research requests. The referrals service routes patient referral information to doctors through Abbott's information network, allowing Abbott to capture important marketing information (such as regional patient concentrations from patient zip codes) and useful tracking data (such as which doctors are getting what referrals) with more accuracy and thoroughness than previous telephone-based methods permitted. The lab status system allows physicians to ask Abbott's labs directly about test status and test results, a time-saving measure that also allows doctors to be better-informed for their patients. The pharmacy system takes orders for medications and advises on new dosages and drugs. Pre-admission and operating room scheduling systems allow physicians' offices to contact hospital staff electronically with information important to hospital workflow and cost control. This job used to be done over the phone; physicians' staff consistently complained of being left on hold and of making multiple calls for one simple task. Consultation requests allow physicians to contact each other, using Abbott's network, to schedule inter-physician consultations. These arrangements increase physicians' revenues and give Abbott managers better data on the flow of consultation work. Lastly, the library application allows physicians to send notes to Abbott's librarians asking for database searches on chosen

medical topics. The results of the searches - article abstracts and studies - are sent back to the physicians through PIN's electronic mail.

Consider PIN as an "emerging" CIS[3]. The system crosses both interorganizational boundaries (from hospital to doctor's offices) and intraorganizational divisions (between hospital departments). Although at present essentially geared to ASCII text transmission, PIN is attempting to initiate access to distributed sources of data and to provide a standardized "data highway" for all of Abbott's constituencies. Abbott management explicitly plans the integration of PIN with future telephone network data switches (in effect combining voice with the CIS network), and plans for an interface with the Data Processing Department's hospital information system (PACE) are in progress.

As Figure 6 shows, PIN does not yet have a Distributed Data Management layer, and many of the "data-source" functions (e.g. operating room scheduling, medical research) still require human intervention for processing information or building queries. Nonetheless, even in the system's present (primitive) form, Unix shell scripts fulfill functions very similar to those performed by the External

[3]The following discussion relies on the systems model introduced in Madnick, Wang, and Frank, "A Conceptual Model for Integrated Autonomous Processing: An International Bank's Experience with Large Databases", Sloan School of Management Working Paper #1866-87, Report #CIS-87-04 "Composite Information Systems Project".

P I N as C I S

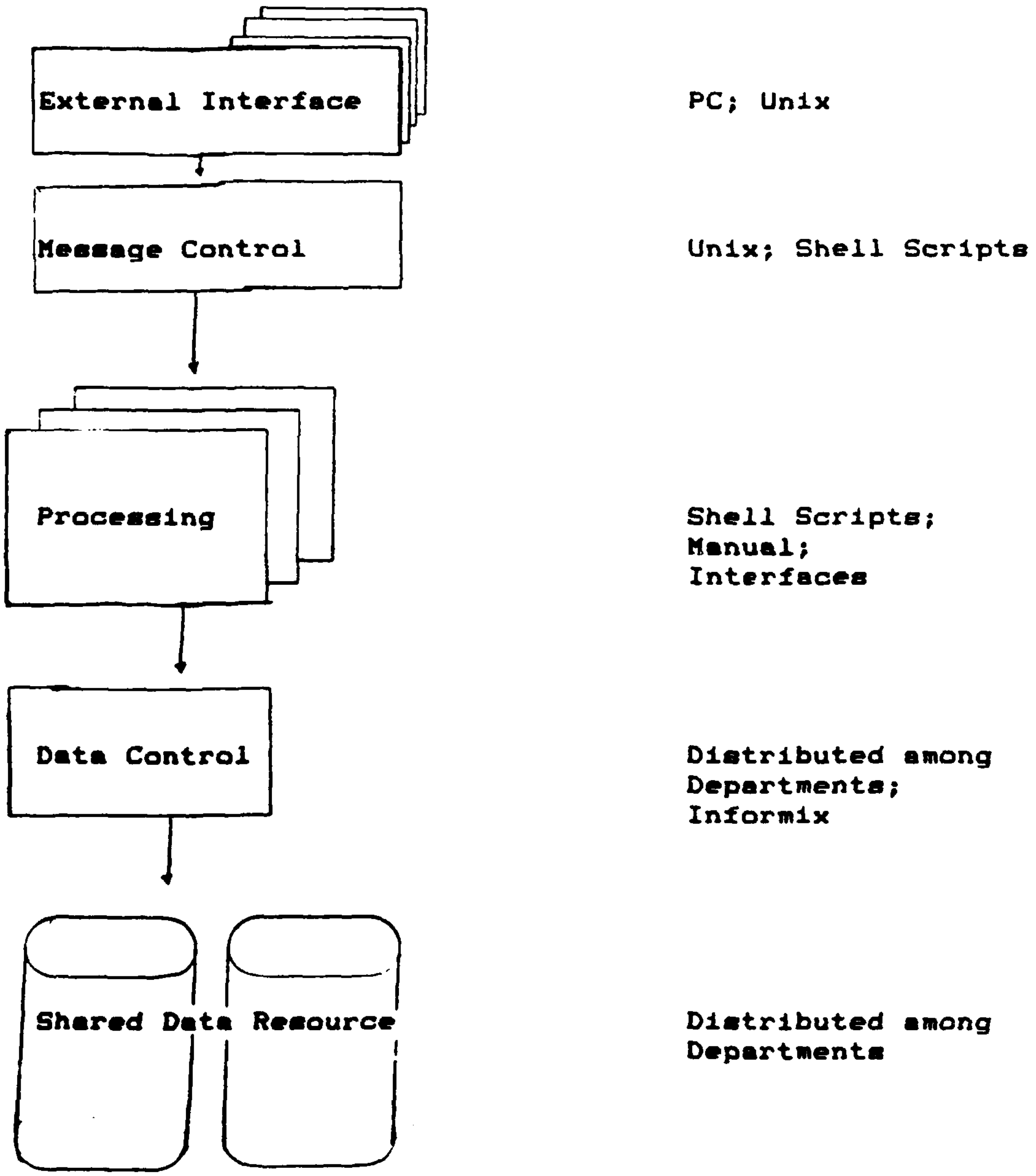

figure 6

Interface, Message Control, and Processing layers suggested by Madnick, Wang, and Frank in their banking study[4].

Viewed technically, PIN exhibits few layers of integrating software and does not use expert systems for mediating between systems (although in PIN humans do perform the same function). Viewed organizationally, however, PIN does perform many of the functions of a full-fleged CIS. It exists to establish connectivity between independent systems[5]. It links strategic goals across organizational constraints using technological innovation[6]. It spans "product areas" within the hospital by providing the physician a common interface to many hospital services[7]. Even in its experimental form PIN exhibits important CIS characteristics:

1. It derives its value from specific cross-boundary linkages (hospital to physician, hospital to hospital, physician to physician).

2. It allows asynchronous coordination of potentially conflicting interests and procedures.

3. Its operating details are largely transparent to its target audience (the physicians).

4. It is used by its developer (the hospital) as a partial solution to specific strategic problems (physician satisfaction, referrals and patient volume, operating cost control).

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[4] Madnick, Wang, and Frank, op. cit., p. 6 and fig. 2.
[5] Madnick and Wang, ibid., p. 5
[6] Madnick and Wang, ibid., p. 5
[7] Madnick and Wang, ibid., p. 8

3. PIN and the CIS Process Model:

Viewing PIN as a CIS further defines aspects of Madnick and Wang's original CIS process model. In that description, the authors propose a four-stage approach to CIS development[8]:

1. Specify strategic goals;
2. Identify an appropriate CIS;
3. Identify technical and organizational problems associated with that CIS;
4. Apply organization theories and information technology to solve the problems.

They produce a schematic of this process which is reproduced here as Figure 7. Abbott's experience implies that each part of Madnick and Wang's model breaks into constituent parts - these are summarized in Figure 8. At the highest level are strategic considerations: business and analytic challenges which hinge on conditions of industry structure. Industry conditions and operating limitations constrain Abbott's strategic choices, and Abbott management's decisions must select from among those choices. The market analysis framework demonstrated in Figures 3 and 4 suggest important components of Abbott's strategic position and the choices which the hospital is making. As strategic goals become better defined, the characteristics of the CIS environment increasingly depend on the organizational problems which impede the execution of

[8] Madnick and Wang, ibid., p. 6

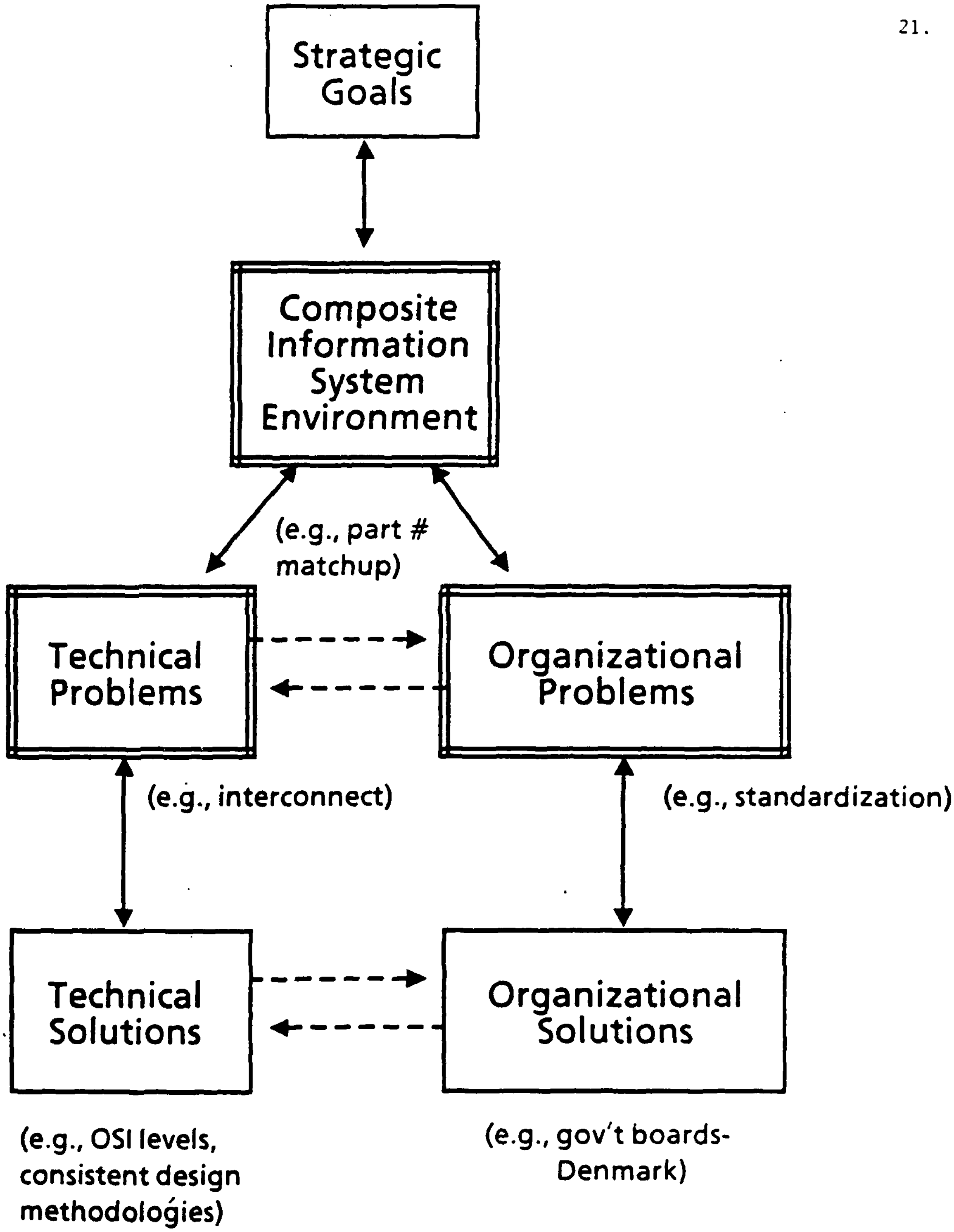

Strategic Goals
Composite Information System Environment
(e.g., part # matchup)
Technical Problems
Organizational Problems
(e.g., interconnect)
(e.g., standardization)
Technical Solutions
Organizational Solutions
(e.g., OSI levels, consistent design methodologies)
(e.g., gov't boards- Denmark)

figure 7

strategic choices. Particularly important at this level are the local interests prevailing within particular organizational boundaries. Solutions to organizational problems of conflicting local interest depend largely on the success with which a CIS can cross such organizational boundaries. Abbott's approach suggests three elements important to building cross-boundary incentives. This paper labels these factors Bidirectional Benefits, Cooperative Payoffs, and Asymmetrical Control. They are explained at length below. At the system-building level come the design and implementation factors which must match technical specifications with organizational characteristics - what is referred to here as "technical match". Each stage of the CIS model breaks into further detail as follows. Abbott's experience provides illustrations:

3.1 Strategic goals (1):

Abbott's managers have a well-defined sense for what competitive factors were key to Abbott's performance. As Figure 4's listing of key strategic factors suggests, they have in effect superimposed a Critical Success Factors approach upon Porter's framework for industry structure[9]. Their decisions demonstrate a thorough understanding of (a) the industry's structure and how it is changing; (b) the

[9]For Rockart's framework see Rockart, John F., "Chief Executives Define Their Own Data Needs", Harvard Business Review, January-February 1982, pp. 82-89.

options available to the hospital; (c) the choices which they prefer among those options; and (d) the consequences implied by those choices. These are listed in Figure 8 as the major components necessary for developing strategic goals: knowledge of industry structure, development of options, informed choices, and understanding of consequences. In Abbott's case, the importance of referrals, for example, is the link they provide through physicians to the potential patient base and so to increased volume. The referrals, consultations, and library research services provided by PIN attempt to strengthen this hospital-physician connection.

3.2 Identify an appropriate CIS (2); Identify technical and organizational problems associated with that CIS (3):

The hospital-physician relationship suggests that a key factor in the success of CIS development lies in the organizational boundaries which system sponsors first choose to cross. Abbott needs to build bridges in key areas between itself and its patient-providers. Abbott's management has closely examined the needs of its physicians and is attempting to construct electronic services that emphasize areas where physician and hospital needs match. One way of expressing this process is to use Porter's "value chain" concept to represent the interests of the

organizations involved[10]. An examination of inter- and intra-organizational value chain linkages is useful for uncovering these "target" cross-boundary connections. Figure 9 suggests how value chain analysis can be a useful tool in revealing organizational problems - particularly the characteristics of localized constituencies, their particular interests, and the threats they perceive from other organizational units. Both hospital operations and the physician's practice can be described as moving through similar stages of providing service and earning surplus or profit. Using an industrial production operation as a metaphor, both hospital and physician engage in:

- Inbound logistics

  For Abbott and its physicians, these activities center on gaining patients through referrals and other sources.

- Operations

  The hospital provides the physicians with services and access to hospital equipment. The physicans provide patients and hospital with diagnosis, presecriptions, and operations.

- Outbound logistics

  Discharges, billing, and cash flow considerations are important aspects of this value chain segment for both parties.

[10] For more on Value Chain descriptions, see Porter, Michael E., Competitive Advantage: Creating and Sustaining Superior Performance, New York: Free Press 1985, chaps. 2-5 and 9-12. For a summary, see Porter, Michael E. and Millar, Victor E., "How Information Gives You Competitive Advantage", Harvard Business Review, July-August 1985, p. 149 - 160.

o Marketing and Infrastructure

Value Chain categories also cover non-direct expenses such as marketing or overhead. Examining these aspects of hospital operations and the physicans' practices highlights the importance of referrals to each party, as well as emphasizing the importance of rapid collections to the hospital and of overhead expenses to the physicans.

The usefulness of this representation arises from mapping PIN applications across the hospital and physician value chains. Figure 9 shows how the PIN Referrals application, for example, provides inbound logistics and marketing benefits to both hospital and doctor. On the one hand it makes the process of collecting patients faster and easier (inbound logistics). On the other PIN improves response time to referrals (making both hospital and physician look better in the patient's eyes) while providing important marketing information about the Minneapolis patient base. Each PIN application is carefully constructed to solve organizational problems by bridging common interests in these value chains. The linkages supported by six PIN services are shown in Figure 9.

3.3 Apply knowledge in organization theories and information technology to solve the problems (4):

In terms of organizational solutions, Value Chain analysis can suggest options and choices. It can show what is important to each player in an inter-organizational situation. It does not, however, suggest specific ways in

SELECTED VALUE CHAIN ITEMS

ABBOTT NORTHWESTERN HOSPITAL

Finance:	Accounting, Collections				SURPLUS
Administration:	Communications (phone, mail)				
(1) Admissions (2) OR Scheduling (1) Referrals	(3) Lab (3) Pharmacy (2) OR Scheduling Diagnostic Equipment CT MRI DSA (5) Research (5) Consultations	(6) Bill Sign-off (6) Discharges	(1) Referrals Name Recognition Reputation Physicians Patients	(1) Referrals Word of Mouth	
INBOUND LOGISTICS	OPERATIONS	OUTBOUND LOGISTICS	PRE-ADMISSION MARKETING	POST-ADMISSION MARKETING	

ABBOTT NORTHWESTERN PHYSICIANS

Infrastructure:	Overhead = 40 - 60 % of revenues				PROFIT
(1) Admissions (2) OR Scheduling (1) Referrals	(3) Procedures (3) Tests (4) Research (5) Consultations (3) Prescriptions Phones Education	Discharge (6) Billing (sign off)	(1) Referrals (1) Location of Practice		
INBOUND LOGISTICS	OPERATIONS	OUTBOUND LOGISTICS	PRE-ADMISSION MARKETING	POST-ADMISSION MARKETING	

LINKAGES

(1) PIN Referrals (3) PIN Lab/Pharm (5) PIN Consultation
(2) PIN OR Schedule (4) PIN Research (6) PIN Sign-offs

figure 9

which a boundary-crossing CIS can improve its chances for success. Abbott's experience suggests that a CIS can do so by emphasizing three characteristics of interorganizational relationships. This paper introduces these characteristics and generalizes them as follows:

3.3.1 Bidirectional benefits and incentives:

CIS appear to be more successful when both parties - on either side of the organizational boundary which the system crosses - clearly see "what's in it for me". This quality could be inherent in the services which the system provides (benefits) or be expressly designed into the system (incentives). The advantages accrue to the parties involved individually; they are tagged "bidirectional" because they accrue to both sides of each boundary (see Figure 10). At Abbott, physicians' practices want to use the pre-admission and operating room scheduling software because it saves them time and frustration on the phone. The doctors' offices run more smoothly, scheduling is more efficient, and busy physicans can spend more time seeing patients and less time dealing with office problems. The hospital gains directly as well: it has a better idea of the scheduling load on its facilities, and it has more flexibility in rescheduling admissions and procedures that was available when requests had to be processed in a single telephone conversation.

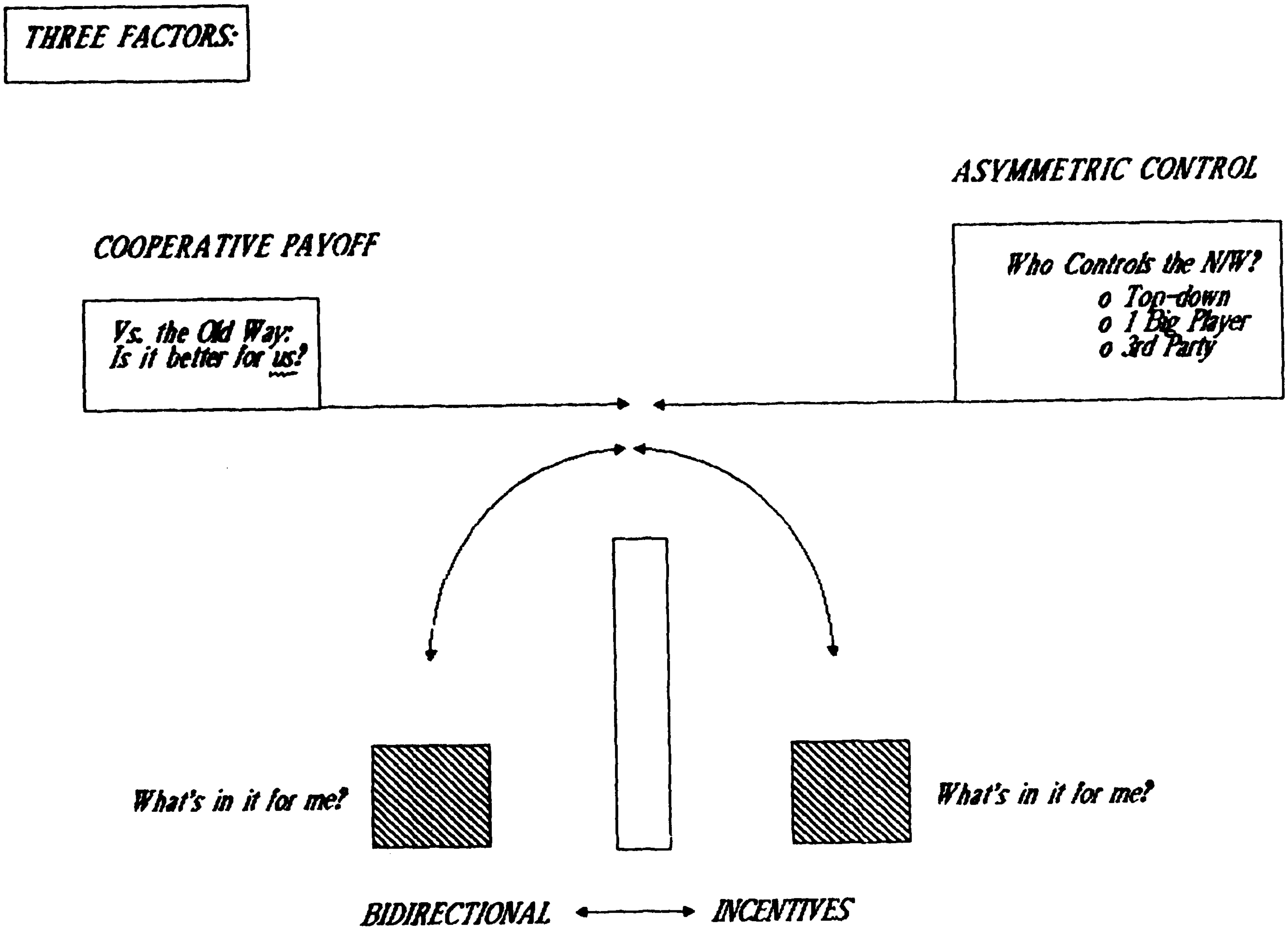

THREE FACTORS:
COOPERATIVE PAYOFF
Vs. the Old Way:
Is it better for us?
ASYMMETRIC CONTROL
Who Controls the N/W?
o Top-down
o 1 Big Player
o 3rd Party
What's in it for me?
What's in it for me?
BIDIRECTIONAL
INCENTIVES

figure 10

Most of the other successful PIN applications show similar bidirectional incentive characteristics.

3.3.2 Cooperative payoffs:

In a sense the idea of cooperative payoffs includes simple cost/benefit tradeoffs: the network must offer more benefits to participants in aggregate than it costs. The terms emphasize, however, that successful CIS seem to offer collective (as opposed to individual) advantages that encourage parties associated with the network to use it. In other words, the network provides something to its participants in aggregate (a "payoff") that comes from using it and in this sense "cooperating" with other players.

This analogy comes from Robert Axelrod's conception of business situations as iterated prisoner-dilemma games. Axelrod describes a "prisoner's dilemma" as follows:

> In a Prisoner's Dilemma game, there are two players. Each has two choices, namely cooperate or defect. Each must make a choice without knowing what the other will do. No matter what the other does, defection yields a higher payoff than cooperation. The dilemma is that if both defect, both do worse than if both had cooperated[11]

In other words, in a Prisoner's Dilemma the short-term payoffs of following localized interests are highest but the long-term payoffs of local optimization are lowest. For a

[11]Axelrod, Robert, The Evolution of Cooperation, New York: Basic Books 1984, p. 8.

CIS to be useful and successful it needs to offer a cooperative payoff as well as localized incentives. The departments using the system need to get more - as a group - out of having the system than out of not having it. We have seen, for example, how PIN's referrals system gives both hospital and doctors individual benefits. One effect of the system is also to make both parties look better to patients (because scheduling and scheduling changes go more smoothly and the patient's experience is more pleasant). Marketing studies have shown the importance of positive word-of-mouth feedback among patients to both hospital and physician marketing efforts. By cooperating through PIN, both hospital and physicians achieve a cooperative payoff that comes with improved reputation in a competitive market.

3.3.3 Asymmetrical Control:

In any CIS setting the issue of who controls the network is important, particularly for the managers attempting to place a network lower in their organization. Network standards can be difficult to implement on a peer-to-peer basis when many disparate groups are involved[12]. The presence of a third party who controls the network but does not have jurisdiction over the messages sent across it

[12] The ideas behind Asymmetrical Control originate with Sirbu, M. and Stewart, S. in Market Structure and the Emergence of Standards, working paper from Department of Engineering and Public Policy, Carnegie-Mellon University.

can often improve the chances of network acceptance under such circumstances.

In a hierarchical setting, network control can be a factor in the strategic uses of CIS. If a manager can keep control of the network that is providing services used by other levels of the organization, he or she may be able to build dependencies that are of strategic importance. Abbott's plans to provide services to its physicians hinge at least in part on a desire to develop in physicians the habit of sending information across the network. Abbott managers expect the market to change over the next five years in ways that will force the hospital to ask physicians for increasing amounts of potentially proprietary data over the network. They anticipate that this task will be easier if physicians are already familiar with the process. Physicians also vary greatly in their systems knowledge and technical interest. Busy with their practices, they probably could not find the time to think about network specifications, much less agree on a single network design. By presenting them with the network as a service and essentially controlling the mechanics of the network completely, Abbott can 1) make PIN easy enough to use so that it will be used and 2) encourage physicans to build habits supportive of electronic data transfer. Both aspects of the network are of strategic interest to the hospital, and both arise from the hospital's asymmetric control over PIN's specifications.

3.3.4 PIN's benefits, payoffs, controls:

Figure 11 categorizes benefits, payoffs, and controls for four selected PIN applications in a "value chain payoff matrix". The table suggests how each party gains from using the network, and can be used to analyze specific inter-organizational value chain linkages for their potential as target CIS target boundary-crossings. The preceding paragraphs have described how the referrals application takes advantage of bidirectional incentives, how scheduling can result in cooperative payoffs, and how the separation of the network itself from the information sent over the network can allow Abbott to gain from the use of asymmetrical controls. Similar results can be observed for the Pharmacy application and for other PIN applications not included in this matrix.

The last column of the matrix, labelled "Factors Supporting Incrementalism" suggests organizational reasons for adopting a highly modularized, incremental, evolutionary approach to implementing each application. It provides evidence for the importance of a careful match between what the organization needs and what the CIS technically provides. In addition to emphasizing benefits and incentives, the system must grow with sensitivity towards those factors which might unduly threaten local interests. For example, it is probably satisfactory for the referrals

VALUE CHAIN PAYOFF MATRIX

PIN Linkages (Applications)	Benefits		Cooperative Payoffs		Support for Asymmetrical Controls		Factors Supporting Incrementalism
	Physicians	Hospital	Physicians	Hospital	Physicians	Hospital	
Referrals & Consultations	Stronger practice; greater revenue.	Higher volume for hospital; greater rev.	Better understanding of hospital's operations & problems.	Tighter linkage to physicians.	Have no time to learn technicalities of computing.	Wants to build physician dependence.	Must not alienate or pressure physicians into using network.
			Savings in time and overhead.	Savings in time and overhead.	Want transparent network.	Can build and service transparent network.	Peer pressure and evolution strongest approaches.
Scheduling (OR, Admission)	More satisfied office staff.	More productive staff.	Savings in time and overhead.	Savings in time and overhead.	Don't have expertise to run network.	Can build and service transparent network.	Office staffs themselves don't know what features they want, but will know as they use system.
			Want satisfied office staff & no way to solve problem.	Want access to physician staff & no way to solve problem.	Don't have consensus to run network.		
Pharmacy	Savings in diagnostic time and costs.	More productive pharmacy.	Won't admit to needing medication advice, but might want some.	Increasing need to reduce pharmacy inventory & costs.	Don't have consensus on medications.	Can ask advisory doctor to add comments even without consensus.	Must distribute formulation and advisory knowledge without leaving impression that physicians have any diagnostic shortcomings.
Laboratory	Better response time for patients.	Better response time for physicians.	Have no control over lab operations.	Have no knowledge of physicians specific needs.	Have neither time nor scale to set up own lab system.	Can operate lab but need response flexibility.	Cannot change lab procedures faster than lab staff can adjust.
		More productive lab.					

figure 11

network to grow slowly - by example rather than by fiat. Forcing the doctors to use the network might convince them that the hospital is trying to take advantage of them, leading to the establishment of informal referral networks that leave Abbott out of the loop.

3.4 Technical-Organizational Match:

For this reason the evolution of any CIS solution requires special attention. The technical and organizational solutions to the CIS problem must match. The habits and incentives supported by technical sides of the system must align with those encouraged by the organizational effects of the system. To the degree that the two are misaligned (not an unlikely occurrence, considering how difficult it is to anticipate all the implications of boundary-crossing systems), the CIS needs the flexibility to evolve to fit the disparity. There are concepts from the strategy literature applicable to these ideas of alignment and incremental evolution[13]. Both could be applied to strategic systems planning in the same way that value chain categories are useful here.

[13] For ideas on alignment, see Culbert, Samuel A. and McDonough, John J., The Invisible War, New York: John Wiley & Sons, 1980. For descriptions of Incrementalism, use Quinn, James Brian, Strategies for Change: Logical Incrementalism, Homewood, Illinois: Richard D. Irwin, Inc. 1980.

PIN shows this match developing. Abbott management emphasizes that the system was first developed with an organizational need in mind, not a technical solution. The system hardware costs less than $100,000 - an inconsequential figure for a hospital that runs two IBM mainframes with a Data Processing support staff of 80 people. Unix mail is at best an interim solution; the network has little security, no data validation, and few of the safeguards of larger systems. The system, however, does match the hospital's organizational needs at the moment: it provides physicians and staff an adequately convenient interface to disparate hospital departments. New applications can be added in hours and days, not weeks. Starting small and growing as physicians' needs grow, the system can evolve over time as the organization changes. As the price of processing power falls, Abbott can afford to subordinate efficient processing for organizational effectiveness.

4. Steps in an Analytical Process:

Figure 12 lists theories and frameworks useful to managers during each phase of a CIS planning process. The first phase, Strategic Goals, suggests methods useful for developing strategies and points of focus for the CIS. We have used Porter's framework to describe Abbott's competitive position with a Buyers-Suppliers-Rivalry

STEPS TO A "PROCESS"

1. Industry structure: CSFs [STRATEGIC GOALS]

2. Value Chain Linkages [ORG. PROBLEMS]

3. Identify

   Bidirectional Benefits
   Cooperative Payoffs
   Asymmetrical Controls

4. Rank Choices by [ORG. SOLUTIONS]

   CSF Linkage
   Benefits
   Payoffs
   Controls
   Modularity/Size/Risk

5. Consider need for Incrementalism

   Stakes
   f($)
   Controls

6. Consider system cost/config. [TECHNICAL SOLNS]

7. Prototype & evolve [TECH-ORG MATCH]

figure 12

industry model. The exercise highlights the compression of Abbott's margins between flattening third-party payment schemes and rising operating costs. It notes the potential local referral problems caused by Abbott's location. The next step superimposes a Critical Success Factors strategic response onto the five forces diagram. It emphasizes the importance of volume to Abbott as a way of fighting the revenue-cost squeeze, and suggests the importance of physician referrals to that strategy. It also adds the chronological aspect of Abbott's situation - the hospital needs to get its physicians used to providing data now so that conversion to bulk data provision in the future (to satisfy third-party payors) will be possible.

Value Chain analysis suggests methods for identifying key organizational problems and potential solutions. Figure 9 diagrams the key value chains involved in the hospital-physician relationship, and shows how selected PIN applications make connections within and between them. Systems features develop to parallel and facilitate these connections.

The Value Chain Payoff Matrix (Figure 11) concentrates on organizational solutions by showing a method for identifying and prioritizing benefits or payoffs arising from value chain linkages. It can suggest areas in which system development should start - areas of highest potential. It also can suggest areas in which the hospital

might benefit from asymmetrical controls. It details potential threats represented by each application to various interested parties - threats which might argue for an evolutionary, incremental system design.

5. Implications for Other Settings:

The conclusions of this paper can be useful in three ways: 1) as further definition of the CIS Process Model; 2) as guidance in steps applicable to CIS-related strategic planning; and 3) as an introduction to the "boundary relationships": bidirectional incentives, cooperative payoffs, and asymmetric controls.

Abbott Northwestern is an interesting illustration for several reasons. First, it deals with a complex market: patients arrive at the hospital largely under the auspices of physicians' practices, and the characteristics leading to patient (as opposed to doctor) hospital preference are largely unknown. Second, it is a non-profit institution: as such it might hold parallels for other non-industrial circumstances. Third, it focuses on a simple network that has complex organizational overtones: PIN is small but reaches across many boundaries, both inter- and intra-organizational.

In considering other complex networks, the use of value chain categories and payoff matricies may be useful in

pinpointing which organizational boundaries to cross first. The benefit, payoff, and control characteristics of each identified boundary may provide important information for how to structure network incentives.

Consider the case defense acquisition. The Office of the Secretary of Defense (OSD) has set up a small task force with responsibility for overseeing all the purchasing efforts now underway at the four major armed services. That task force needs information currently held by the Services in order to fulfull even its monitoring responsibilities, much less its coordination tasks. The Services fear loss of control of their own acquisitions efforts if they surrender the information. The Services also face an increasingly complex task of communicating digital information across organizational boundaries to contractors, sub-contractors, and field commands. If the OSD can learn enough about local organizational conditions to be able to specify workable bidirectional incentives, it might be able to gain access to some of the information it wants by offering a network that satisfies the Services needs. Knowing these characteristics also makes it possible to determine some realistic estimate of possible cooperative payoffs. Lastly, understanding the extent to which asymmetrical control can be used to advantage may further the standardization of communications among and between services. Value chain and payoff matrix categories may provide a way of identifying areas in which a CIS network could improve the sitation should OSD orders for

data surface incorrect or useless information provided by defensive Service departments. This kind of segmentation may lend some structure to OSD's broad CIS problem.

6. Next Steps:

Abbott Northwestern provides illustration, not externally valid data. To determine the extent to which benefits, payoffs, and controls really affect organizational boundary-crossings requires several sequential research projects. One might suggest a series of studies leading to the definition of a rigorous experimental methodology:

1. Begin with definitional case studies in different industries and areas in order to express CIS components with more precision;

2. Continue with field studies within related companies or industries. These studies can validate concepts suggested in the case studies by applying them to a wider sample;

3. Focus the definitions with field experiments if companies can be located which are adopting CIS. Try to track phases of CIS adoption through those companies.

4. End with laboratory experiments to determine the range of defined CIS characteristics. These experiments might, for example, set up a crossboundary task and vary the parameters affecting bidirectional incentives, cooperative payoffs, and asymmetrical controls.

7. Conclusions:

This paper 1) suggests further definitions for the elements of Madnick and Wang's CIS process model; 2)

introduces the concepts of bidirectional benefits, cooperative payoffs, and asymmetrical control as important elements for CIS design in boundary-crossing situations; and 3) suggests, by implication, an analytical process useful for planning the strategic aspects of CIS designs. Illustrations are drawn from the experience of Abbott Northwestern Hospital with a prototype CIS.

The paper builds on existing theory in several areas. Madnick and Wang provide the original CIS model. Porter, Rockart, and Quinn supply core ideas behind the use of value chains, critical success factors, and incremental development in CIS design. Axelrod and Sirbu introduce the concepts of cooperative payoffs and asymmetrical controls.

Composite information systems cross organizational boundaries by definition. Each boundary crossing implies elements of bidirectional benefits, cooperative payoffs, and asymmetrical controls. Bidirectional benefits affect organizational units individually, cooperative payoffs benefit the organization at an aggregate level, and asymmetric controls allow for the development of strategic dependencies. A CIS can emphasize the positive aspects of these relationships in order to become more effective. Abbott Northwestern's PIN network provides an example of an organization doing so for strategic reasons.

PART B:

ABBOTT NORTHWESTERN HOSPITAL

Part B treats the history, competitive background, and organizational circumstances of PIN's development in some detail. It is intended to give the reader a better conception of the Abbott's business position and management approach as well as a perspective on the part played by PIN as an emerging CIS.

Abbott Northwestern is the largest tertiary care hospital in the Minneapolis-St. Paul metropolitan health care market and the flagship facility of LifeSpan, Inc., the second-largest multi-hospital system in the Twin Cities region. With 774 beds, 4,000 employees, over 25 fully equipped operating suites, 1,033 practicing physicians, ten major specialty clinics, and operating revenues in excess of $225 million annually, Abbott ranks in the top five percent of U. S. health care delivery institutions in size and reputation. As a tertiary care hospital Abbott is known nationally for its cardiology specialties and is one of the four percent of American hospitals to support a radiology residency program. Operating margin for the year 1986 exceeded $4.5 million, a comfortable surplus of .002% of revenues and suitable to Abbott's status as a non-profit institution.

Abbott operates at the center of one of the most competitive health care markets in the United States. In the 1920s and 30s farmers and blue-collar workers in the area were already depending on cooperative medical plans. Group Health Plan of Minnesota exposed current-generation residents to the concept of pre-paid healthcare as early as 1957. During the decade of the 1970s, HMO's entered the Minnesota market and enrollments grew explosively to the point where nearly 50% of the area's residents are HMO enrollees. This level compares with approximately 10% for the nation in aggregate. Only California and Florida can compare in HMO penetration.

HMOs, in cooperation with Minneapolis' strong concentration of large firms (the area ranks third behind New York and Pittsburgh as a headquarters site for Fortune 500 corporations), have become powerful buyers in the Minnesota market. Controlling large pools of potential payments, the healthcare plans can put extreme pressure on hospitals to negotiate flat fees per patient and/or procedure. The resulting squeeze on hospital cost structures has resulted in the consolidation of many smaller Minneapolis-based hospitals.

The area is now dominated by four major multi-hospital systems, which represent over 41% of the 10,000 licensed beds in the region. Among these, Abbott Northwestern ranks third in number of beds, second in revenues, and first in

inpatient census. Where the average regional hospital filled only 47% of its beds in 1986, Abbott utilized 71%. The closest multi-hospital competitor reached 68%. With large fixed costs to support and reimbursement pressure from third-party insurers rising, patient volume has become a critical indicator of competitive success in the Minneapolis marketplace. Among the non-profit institutions, the battle for market share now implies a battle for survival.

ABBOTT ORGANIZATION

Abbott management has long believed that a hospital is only as good as the physicians practicing within it. This attitude has led to careful treatment of physicians as the hospital's "best customers" - an approach not typical of the industry. Physicians act in a consulting capacity for many decisions made by hospital administrators and are active members of most management committees. Abbott executives market the hospital's services both externally - to the community - and internally - to Abbott's doctors. Formal and informal connections between the administrators and the physicians are fostered at all levels.

Unlike most hospitals, Abbott's managerial staff is not split between "medical" and "operational" responsibilities. At Abbott, most administrators handle both medical and "logistical" departments. The Senior Administrator in charge of the Surgery and Cancer programs, for example, also

supervises Telecommunications and Laboratory. The Associate Adminstrator responsible for Radiology also oversees Material Services and Medical Records. This dual focus works to push an appreciation for the interrelationship between medical and operational issues deep into the administrative hierarchy.

VOLUME, COST, AND PATIENT REFERRALS

Key among these interrelationships are the linkages between cost, volume, physician satisfaction, and patient referrals. The connections between these elements make referrals of strategic importance. According to Abbott management, this key feature has emerged as follows:

1. Pressure from fixed-fee third-party payment schemes reduces the hospital's margins on high-risk specialties. With lower margins Abbott's financial slack disappears and cost reduction becomes of critical importance. Unfortunately the same operations (such as catheterized coronary bypass surgery) in which Abbott specializes are among those in the most volatile and expensive category. They also tend to be the newest, most prestigious treatments - and exactly those which Abbott must emphasize to attract the best physicians.

2. With increasing cost pressure and flatter repayments, volume offers the only way to gain economies of scale from Abbott's high overhead levels. The hospital has invested approximately $139,000 in fixed assets per practicing physician. The more patients the physician refers to Abbott, the more productive this overhead can be. Abbott's market reserch shows that in the Minneapolis area, physicians select the hospital for tertiary care more than 60% of the time (vs. a national average of 50%). Although most physicians will give a patient a choice of at least two hospitals, Abbott's size and reputation allows it to dominate once it makes the list.

3. The relationship of physician to referrals makes it critical to Abbott to remain attractive to its physicians. Satisfying the doctors means paying close attention to their business problems as well as finding ways to finance the newest in diagnostic equipment.

4. More physicians "loyal" to Abbott means improving patient volume. Patients satisfied with their treatment at Abbott set up a strong word-of-mouth network through their family and acquaintances. Although the exact degree of the trial/referral/return connection has proved impossible to quantify, Abbott executives are convinced that this two-part approach extends the hospital's penetration into the referral base and improves market share.

EARLY NETWORKS

Over the past five years Abbott has experimented with ways to provide service to physicians so as to improve both satisfaction and referrals. Marketing programs have also been developed which attempt to link patients with physicians' practices.

The first opportunity occured in 1981 when one Abbott manager noticed repeated complaints among physicians that their answering services were not performing adequately. At that time all the doctors in the hospital used Hennepin Country Answering Service for their practices. Many calls were being missed and messages left with doctors were garbled or worse. The Abbott executive involved (who worked in the Medical Council Affairs side of the hospital) kept hearing answering service horror stories from the doctors over lunch in the doctors' dining room. She realized from their comments that most doctors considered their answering service the logistical heart of their

practice. She asked the hospital's Director of Telecommunications to look into the costs of setting up an in-house answering service. She then went to Abbott's CEO with a request for a pilot study. Over the next 16 months, first five and then ten cardiologists used Abbott's service. After some initial problems, the pilot was successful. In 1987 500 doctors - roughly half of Abbott's practicing physicians - rely on Abbott to answer their phones. Abbott charges $47 per month for the service. The nearest commercial competitor charges $53.

The hospital also started working the patient-physican equation from the patient side. In 1982 Abbott inaugurated its Medformation Program, a coordinated set of public speaking engagements, free clinics (in such areas as pre-parental education), hospital tours, informational pamphlets, and a Medformation toll-free phone number. At all meetings and in all advertising, participants were encouraged to call the Medformation number if they had questions - or if they needed a physician referral. The number was staffed by two operators and soon was handling 20-25 calls per day. The 400-500 calls per month generated a significant number of referrals, which Abbott passed on to "loyal" doctors.

THE PIN NETWORK

By 1984 it was becoming clear to Abbott's top management that the healthcare market had changed for good and that volume and market share were going to drive competition in the Minneapolis region. In addition, there were signs of two other trends. First, it appeared that the patient-provider organizations (HMOs and corporate health plans) were going to press the hospital for more procedure- and physician-based productivity measurements. Although such demands appeared to remain several years away, Abbott managers realized that 1) their present systems offered no way to provide such information and 2) that the information the patient-providers wanted about physicians was not information the physicians wanted to give up.

Second, the doctor's dining room resounded to complaints about rising overhead in physicians' practices. With increasing paperwork requirements forced by the pressure of malpractice, higher malpractice premiums, clerical salaries adjusting for the inflation of the late 1970s, and higher office expenses of all types, overhead was exceeding 40% of a physician's revenues (it would reach 60% by 1987). These factors led to a new focus on the part of many physicians - a focus on cutting the costs of their own businesses. This meant looking more closely at the costs of running their own offices.

As she had with the answering service project, the Abbott executive who learned of these complaints approached the Telecommunications Director with ideas for solving the doctors' problem. The two of them brought a proposal before Abbott's CEO, who also saw in the concept a means for capturing the data Abbott would need in future competitive bids with patient-providers.

The result of their collaboration was PIN - the Professional Information Network. In its pilot stage, PIN offers eight services:

1. Electronic Mail.

The nature of their work makes it difficult for physicians to work in one place, and while the paging system is supposed to alleviate this problem it does not always succeed. As one senior administrator noted,

> Physicians are phenomenally difficult to get ahold of. They don't always answer their pagers. What generally happens is that they listen to one trusted secretary in their office. They're so busy that they say, "Here - just tell Kathy and Kathy'll tell me where to be when...". When I hear that, Kathy's name immediately goes into my Rolodex - because I know that's the only way I'm ever going to reach that doctor...

PIN's electronic mail network links physicians' offices with the hospital, with each other, and even with some HMOs. The result has been much better communication of routine news between all parties. This link has been particularlly important because many of Abbott's non-surgical physicians have been forced by industry changes to spend less time in the hospital and more in their clinics. The mail network can reach them where pagers can't.

2. Calendar.

Each physician tracks the schedule of committee meetings and Continuing Medical Education (CME) presentations. Before PIN these schedules were distributed by newsletter, and the most recent copies

were often lost. Abbott still sends this newsletter to its doctors, but now that information is repeated in a bulletin-board section of PIN. The listings are always up to date, and the system provides a good way for doctors new to PIN to get immediate, non-intimidating use out of the system: Calendar screens look like the newsletter pages they have been reading for years.

3. Library.

PIN provides an on-screen form which physicians can fill out describing research topics of interest on a particular case. The completed form is delivered to the research staff (two full-time-equivalent employees) in Abbott's library, who have access to the major on-line medical databases. They can search for article abstracts and references related to the physician's interest, assemble the material they collect into a file on the PIN system, and then send it to the physician through the electronic mail network.

This system has proven particularly attractive to new doctors considering Abbott as a place to base a practice. These younger MDs usually come from a medical school which had a search service (although not necessarily electronic mail delivery), and they feel comfortable with computers. Indeed, for them this service is a prestigious selling point.

4. Lab results.

Lab tests are typically ordered by mail or pneumatic tube system. Results are returned by mail or courier. When the labs get backed up, delays can stretch for several days on some tests - during which time the physician has no idea of the test's progress. PIN allows for immediate checks on the status of lab results, and removes the delay of physical mail-handling once the tests are completed. The system reduces the number of times a doctor is embarrassed in front of a patient because lab results are inexplicably delayed, lost or incomplete. In short, the lab connection saves doctors' time and helps them to look good in front of their clients.

5. Pharmacy.

Choosing a the correct drug and dosage from among the increasing numbers of alternatives available is a steadily more complicated task. Pressed for time, many doctors develop over the course of several years "favorite" drugs and dosages. Some of these are less effective than other alternatives, and some are more expensive for the hospital pharmacy to provide than

others. The Pharmacy system provides a way for Abbott to suggest alternative dosages or drugs to the doctors in a non-threatening way. The doctors are free to request their own choice or to adapt their order to that suggested. The system also remembers personalized directions for each patient, allowing doctors to provide small but helpful touches to dosages and prescriptions. Lastly, the system provides a record of the latest formulations available so that a physician can refresh his or her memory on particular details.

6. Operating room scheduling.

Scheduling Abbott's 26 operating rooms (ORs) is a major procedural bottleneck. For the hospital, it is critically important to run the operating suites at full capacity - they are among the most expensive parts of the facility. For a physician's office, it is critically important to schedule operations at convenient times for the patient and the doctor, to do so rapidly, and to do so in a manner that allows for flexible schedule changes if needed.

The present system, as in most hospitals, forces a doctor's office to telephone the operating room scheduling staff. Inevitably long periods of time are spent on hold. Since most doctors want to schedule operations early in the morning, scheduling during peak periods is particularly difficult. Unforseen delays, scheduling mistakes, and rigid completed schedules form a major frustration for doctors and their office staffs. Problems reflect poorly on Abbott and its adminstrators.

PIN changes scheduling workflow. Office staff members fill out an on-screen form which is then immediately printed out on a printer in the OR scheduling office. There Abbott staffers build the schedule as usual. Assigned times are communicated through the e-mail network. The new system has several advantages: 1) doctors' staffers are no longer lost in "on-hold" limbo; 2) Abbott schedulers have a better idea of the load at critical times, and can often shift room assignments or make other adjustments (not all the operating suites are the same size) in order to increase utilization; 3) as a result OR schedules appear more flexible; and 4) doctors are getting scheduling results back faster. While Abbott cannot yet quantify the improvments made possible by the system, improved relations with doctors' offices are already evident. Improved relations with physicians' offices usually means more satisfied physicians.

7. Consultations.

An increasing part of physician-to-physician business at Abbott consists of consultations, where one physician will charge a fee for a quick examination of another's patient. Sometimes consultations are requested by the doctor and sometimes by the patient. They are usually prevalent in difficult cases - i.e. case which end up being expensive for the hospital to support. Typically consultations are requested over tl e telephone, which means that physicians' office staffs are involved and that all the same problems of telephone traffic, missed messages, and frustrated staff members arise. Abbott is usually left out of the loop, and does not know which doctors are consulting which.

PIN provides an on-screen form for requesting consultations. The requestor fills out the form, hits the return key, and the message is automatically delivered to the recipient physician's office terminal. Delays are less frequent. More importantly from Abbott's point of view, the hospital now has a record of every consultation requested and billed. It can assemble quantitative information on exactly which physicians are most highly regarded and which are requesting the most consultations. It can tell which types of cases are the most likely to generate consultation business, and so flag cases that might generate above-average expense levels. Against the competitive background of the Minneapolis market, such information takes on strategic importance.

8. Referrals.

PIN gives Medformation Line staff an on-screen form to fill out with each referral call. The form captures names, addresses, zip codes, and the type of specialty requested. It is a natural extension of the hospital's efforts to place patients with doctors who practice near them. The PIN form allows for more consistent collection of this informtion.

This growing pool of data is becoming an interesting marketing tool for Abbott. Not only can the hospital track exactly how many referrals it is giving to each doctor, but it knows where within the Minneapolis area those referrals are coming from (by zip code). It has a mailing list of all those patients and can see if they eventually pass through Abbott facilities. It knows what medical specialties they were searching for. By matching specialty with zip code, Abbott can locate areas in the city which are short of doctors and may be fertile territory for opening a new practice. At the

same time the hospital can use its knowledge of physician consultations to pinpoint the best of its doctors, as well using its various scheduling services to determine which doctors bring the most patients through the hospital. Cross-tabulation of all these factors provides a picture of potential high-quality, loyal "Abbott" physicians. Abbott has made a conscious decision to identify such physicians among its younger doctors, and to "invest" in such individuals by suggesting locations in which they might open a practice. If the doctor is interested, Abbott may even help finance the practice until the doctor's own patient volume becomes high enough to cover costs.

Through these eight subsystems, the Professional Information Network seeks several objectives:

1. It seeks to put Abbott into the doctors' information loop in places it did not participate before, and to do so by providing a useful service. Abbott management hopes that by doing so PIN will make physicians more at ease with sharing data with the hospital. The most optimistic scenario suggests that physicians will decide it is more cost-effective to keep all their practice data with the hospital, and essentially use Abbott to automate their practices. Such a result is unlikely in the near term, but it represents Abbott's potential target.

2. It seeks to reduce physicians' overhead expenses by speeding up mundane office tasks which involve the hospital. Scheduling, lab results, and research now all make the hospital critical to the service loop and project Abbott as more responsive to doctors' needs. The lose-lose situations of logistical frustrations and bottlenecks disappear.

3. It seeks to reduce operating costs. Improved scheduling, more efficient lab testing, and better pharmacy utilization may be the direct result of the PIN network.

PIN: COSTS AND RESULTS

To date PIN does appear to be accomplishing its objectives. Increasing numbers of doctors are signing on to the network (the pilot began with approximately 100), and

positive stories are circulating among the physicians and their staffs. It is too early to tell whether the system will result in dramatic cost savings, although many scheduling tasks are executing more smoothly.

It is interesting to note that in traditional data processing terms PIN costs next to nothing. The system is essentially a layer that overlays existing data bases and programs on widely dispersed computers. PIN itself runs on three AT&T 3B computers, each the size of a large PC. They did not cost more than $90,000 total (including software), and are stuffed into a closet in the office of the administrator who first thought of the PIN idea. All of PIN's screens and interfaces are written as Unix shell routines; designing and coding a new screen usually takes from a few hours to an afternoon. New services can be designed, tested, and added within a week to ten days. The PIN communications packages - mail, referrals, library research, lab results, consultations, scheduling - all merely add different screens and interfaces to the mail system already built into Unix. The entire PIN network was implemented using Abbott's existing telephone switch and existing wiring. Abbott charges doctors $1,300 for a modem and dumb terminal. For those who have a PC (and by now most do) charges are even lower.

These costs and this flexibility compare with the proposal originally suggested by Abbott's Data Processing

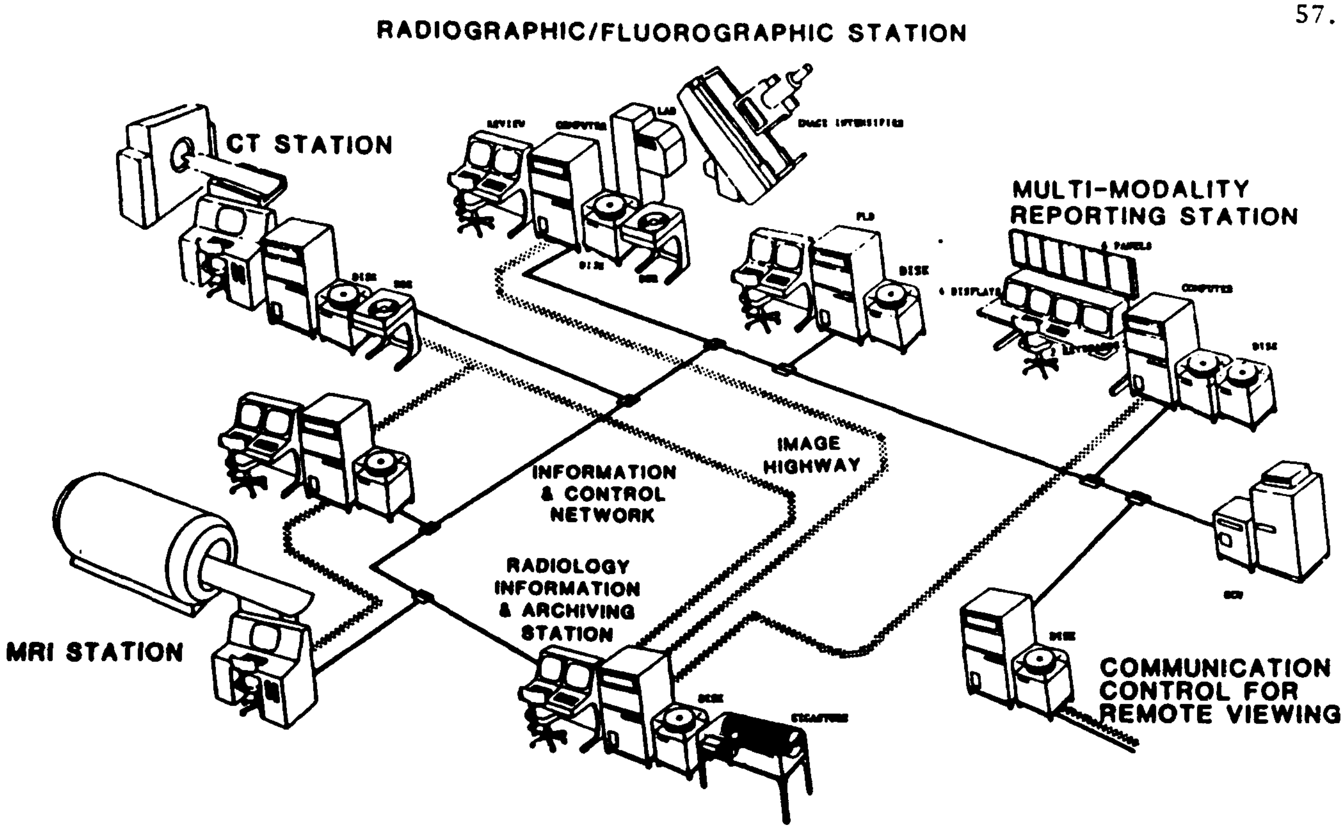
Department to develop an integrated data base to provide PIN's functions. The effort was to have taken 40 of DP's 80 programmers two years to complete. If it worked, it would have been a state of the art, leading-edge system. It would have cost at least two orders of magnitude more than PIN has to date.

Plans are underway to increase the PIN's contributions to cash flow. PIN's next system will involve the transmission of physicians' "electronic signatures" on patient bills. By law Abbott cannot send out billings until the physician has reviewed and signed off on lists of charges and procedures undertaken. In practice this is normally a formality. In the rush of medical events that the physician usually considers more important, signing bills is usually forgotten. The result is that Abbott's spread between accounts receivable and payable (expressed in days to collection) approaches the industry average for non-profit hospitals of 17 days. The similar figure for for-profit chains is 3.5 days. Abbott managers anticipate that the ability to collect physician signatures across PIN could drop the spread by half if fully used by the hospital's doctors. Considering that Abbott was carrying over $60 million in receivables as of the end of 1986, the cash flow implications of this improvement are large and positive.

COMMVIEW

With the PIN prototye showing signs of success, Abbott's management is considering other areas in which systems might be used strategically. One of these is Radiology - specifically Picture Archiving and Communications Systems (PACS). A PACS replaces x-ray film by capturing a digitized radiological image and storing it on disk. The image can be recalled, displayed on a series of cathode-ray tubes, and manipulated in ways that film-based images cannot. PACS work best with current sophisticated diagnostic tools such as Magnetic Resonance Imagers (MRI) and Computed Tomography (CT) Scanners that take a digitized image during their procedures. In routine radiography images are captured directly to film without being digitized first, and additional PACS equipment is required to digitize the picture. Figure 13 shows a typical PACS network installed in a radiology department.

Abbott has invested heavily in the most modern radiological diagnostic equipment. The hospital has two CT scanners (worth about $1 million in aggregate) and was one of the first in Minnesota to install high-performance MRI. The MRI equipment, utilizing a 15-foot-tall electromagnet weighing approximately 3 tons, cost in excess of $3 million. All three facilities are used for sophisticated specialties such as Neuro-radiology, covering cases which other local hospitals can't handle. Competition for such services is



DOR - DIGITAL OPTICAL RECORDER
AD - LARGE AREA DETECTOR
HCU - HARD COPY UNIT
FLD - FILM DIGITIZER

figure 13

PACS CONCEPT

From *The Digital Imaging Network Report* - reprinted by permission of the Center for Devices and Radiological Health

beginning to surface at two of the other large Minnesota multi-hospital chains.

Abbott faces two major problems with its radiology facilities. The first is cost-based. While radiology procedures generate more than $35 million per year in revenues, the area has consumed the largest part of the hospital's equipment budget and has operating costs which are growing rapidly. Abbott runs over 400 radiological exams per day, and 79% of these are film-based. At approximately 6.5 images taken per exam, the area generates 2,600 images per day and over three-quarters of a million pieces of film per working year. The high-resolution, high-performance photographic film sheets used in these procedures cost in excess of $2.00 per sheet. In one year film costs alone exceed $1.5 million. Legal archiving requirements force the hospital to store several year's worth of film on-site and in nearby warehouses. Merely handling the film is a job which requires seven file clerks, who receive aggregate wages in excess of $105,000 per year. Retrieving films from local storage takes time, causes delays, and often frustrates doctors who receive films for the wrong patient or are told that images are temporarily misplaced. These problems are particularly acute because Abbott's radiologists have case loads that are far above the hospital average. They confer with physicians of other specialties on many cases and have among the most active consultation practices.

The second problem is volume-based and strategic. Because Radiology is among the highest-cost areas of the hospital, procedure volume is especially critical there. Any methods that increase utilization of radiology facilities or of Abbott radiologists (who will, over time, bring consultation cases to Abbott equipment) is of great interest to Abbott management. PACS offers a way for Abbott to extend its reach beyond its geographic area. Many smaller hospitals outside of the Twin Cities area need additional radiology expertise. The only way to get consultation from radiological specialists is to mail films into Minneapolis and make appointments to confer with Abbot doctors on the telephone. As was clear in the PIN example, this is much easier said than done. The regional radiology consultation system has not been working to the degree Abbott management thinks it could. Abbott management is investigating the possibility of connecting Abbott Radiologists with community hospitals by PACS links, and using telephone lines to exchange digitized images. This procedure would greatly enhance Abbott's regional reputation and forge stronger relationships with a large number of regional hospitals. Abbott managers believe that such links would enable Abbott to gain increased numbers of referrals and improved market share. Figure 14 diagrams Abbott's PACS effort. The current system serves the Lower Back Clinic and Children's Hospital (an affiliate located on Abbott's campus). The future system is expected to link images and

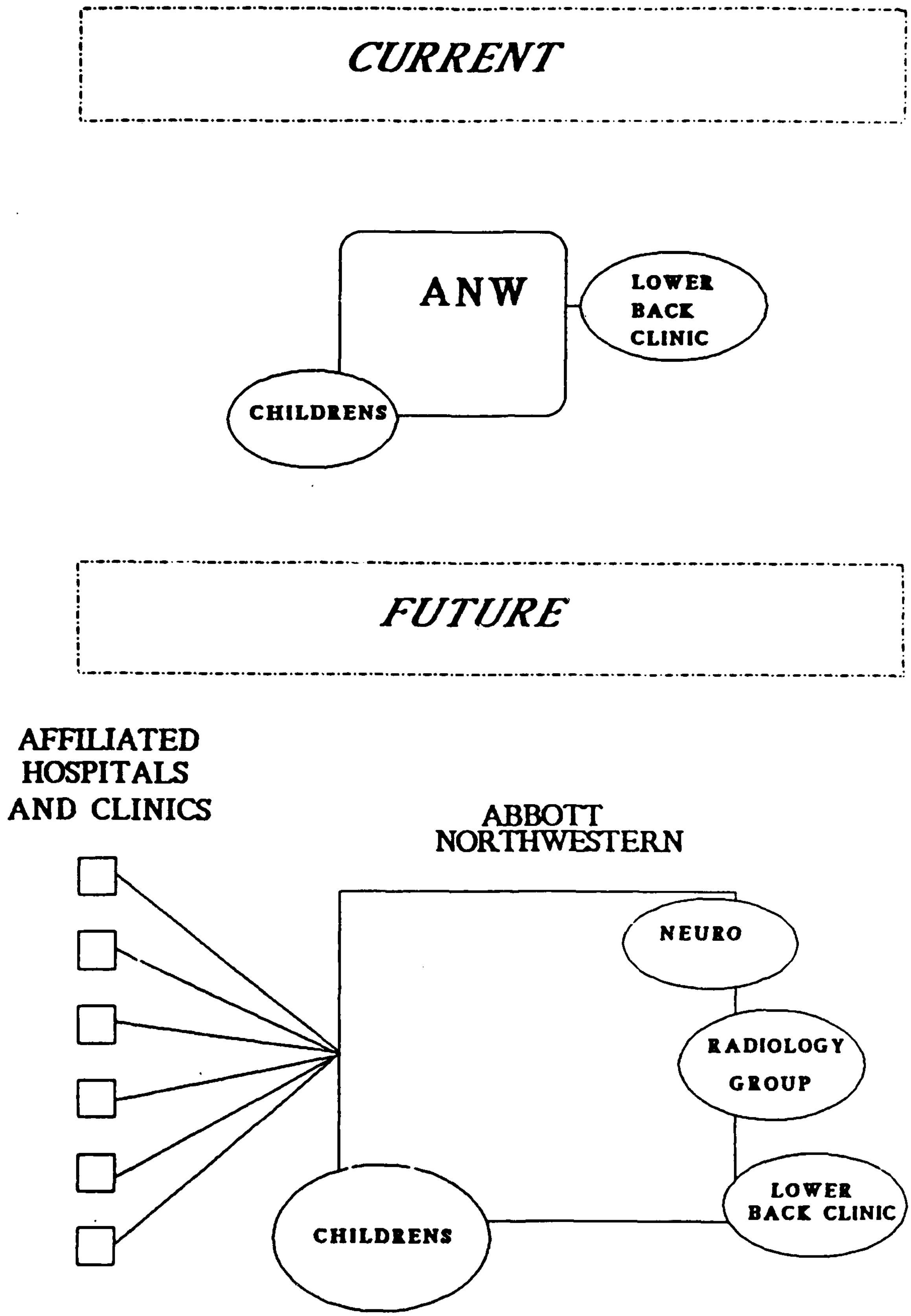

CURRENT
ANW
LOWER BACK CLINIC
CHILDRENS
FUTURE
AFFILIATED HOSPITALS AND CLINICS
ABBOTT NORTHWESTERN
NEURO
RADIOLOGY GROUP
LOWER BACK CLINIC
CHILDRENS

figure 14

consultations with affiliated hospitals and clinics statewide.

Abbott is a beta site for the development of the CommView system, an experimental PACS introduced in 1985 by AT&T Bell Laboratories. Consisting of several customized minicomputers and monitors, over 1 million lines of C code, and a leading-edge in-hospital optical-fiber network, CommView represents more than two years of work by 125 Bell Labs engineers. The product presses the state of the art in numerous areas - among them in its interface with digital diagnostic systems (CT, MRI), in its screen resolution (1024 x 1024 pixels, moving to 2048 x 2048), in its use of 175-megabyte 5.25" internal disk drives, and in its reliance on an optical-disk "jukebox" for more than a gigabyte of disk storage. A working configuration of CommView modules costs more than $1 million dollars; a display workstation alone (which includes upwards of three large screens and computers to drive them) costs more than $300,000. A brochure describing the product is attached.

It is clear that a commercialized CommView system would have a number of advantages. It would be state of the art and would attract doctors to Abbott. It would save film costs and shorten film retrieval times. Telecommunications links to regional hospitals would bring referral business and ultimately lead to increased volume at Abbott. In the near term, however, the system represents a major strategic

gamble. Over the next two years full-featured PACS such as CommView are likely to remain uneconomic, particularly while film and digital systems run in parallel. Technically, images require large volumes of storage. Fully replacing film would require over 20 gigabytes of data storage per year, even using the advanced image compression techniques in which the Labs engineers excel. Storage systems which can handle that much data are only just beginning to move from the laboratory to the marketplace. Linking Abbott with regional hospitals and sending images over telephone wires would probably require dedicated data switches or conditioned lines, and may have to wait until full digital service is installed by Northwestern Bell. Even then there is no guarantee that communications capacity will be able to handle the volumes of bit-traffic if the links become popular and many images are transferred.

SYSTEMS AND STRATEGY

Abbott Northwestern has spent five years moving towards strategic information systems. Its first venture into the telephone network convinced hospital managers that the provision of improved services to Abbott physicians was in the long-term strategic interests of the institution. Its next step, PIN, was an inexpensive pilot suited to trying out some of these ideas. With PIN Abbott administrators advance what looks like a support system to Abbott's

doctors; yet inside they have hidden plans for tactical cost reduction, strategic links to referrals for increased market share, and a strategic tilt towards increase physician dependency.

CommView takes a riskier step. Now Abbott is betting significant amounts of money. The technology is new to Abbott and to Bell Labs. The system is larger than anything but the largest mainframe projects that Abbott has yet undertaken. The specifications of the PACS radiological service and the intra-state linkages are not fully defined. Abbott managers have no real way of checking whether the assertions of the Labs systems developers that the system will be functional and completed on time are reasonable or not. CommView is a risky "big project-unstructured problem" effort. It is a measure of Abbott management's agressive dedication to Abbott's doctors and to increasing Abbott's market share that the project continues.

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INTERORGANIZATIONAL INFORMATION SYSTEMS VIA INFORMATION TECHNOLOGY: A NETWORK PERSPECTIVE

NITIN NOHRIA AND N. VENKATRAMAN

The implementation and efficient operation of distributed, heterogeneous database management systems assumes sustained efforts and cooperation between multiple organizations. The constitution and functioning of inter-organizational networks is an area of active research.

The history of organizational theory can be divided into three periods. In the first period, organizations were perceived as independent bodies, and internal factors were deemed to be prime agents for causing change. The second period saw an emphasis on the environmental aspects, and an increased emphasis on the role of external factors. The third period, which still continues, has witnessed shifting of the focus to the inherent interdependencies of organizations and environments along technical, social, and cultural dimensions.

The introduction of inter-organizational information networks has the potential of making significant changes within organizations themselves, as well as the manner organizations conduct their business. Historically, organizational issues pertaining to the effective management of an information system have been largely studied from the focal point of a single unit. At the next higher level of complexity there are data environments which cut across several sub-units differing in their tasks and roles, as well as in organizational structures and processes. Finally, at the highest level of complexity, there are inter-organizational systems. The current thinking is that in some cases a firm may be able to realize competitive advantage in the market through the use of such systems, while in other cases the deployment of such systems merely reduces operational inefficiencies in the administration of market transactions.

The above ideas are studied in this technical report. It appears that several major strategic and organizational issues need to be resolved to attain full benefits from shared inter-organizational information resources.

TECHNICAL REPORT #8

INTRODUCTION

The advent of information technology (IT) as an active communication and coordination medium presents possibilities that could alter the fundamental precepts of organizational strategy and design. This potential is readily evident in the emergence of electronic markets such as NASDAQ, electronic inter-organizational integrated manufacturing systems such as the Manufacturing Automation Protocol (MAP) at General Motors, and electronic intra-organizational networks such as the Global Processing System (GPS) at Citibank. Indeed, the promise of IT has led certain researchers to suggest that the organization of economic activity may now be conceived as the choice between electronic markets and hierarchies (Malone et al, 1985).[1]

Over the last few years, several organizations have found it advantageous to design and implement information systems that extend beyond their traditional boundaries. Typically, such systems are aimed at streamlining transaction processing activities such as order-entry, sharing of bill-of-materials, invoicing and billing (see for instance, Cash and Konsynski, 1985; Barrett and Konsynski, 1982). Moreover, we are beginning to see the emergence of such systems across a wide range of industries (see Table 1). While we witness an increase in the number and diversity of such systems in the marketplace, much of the literature in this area is still descriptive in nature focusing on the technical and operational details. There has been little attempt to position the role of such systems in the broader fabric of the 'organizational field' that reflects the multiplicity of organizations involved in the creation and maintenance of such systems.

This paper is predicated on a fundamental premise that research into the nature and impact of the emerging interorganizational information systems and networks (made possible due to significant capabilities offered by information technologies) should be anchored in relation to the changing

Table 1: A Profile of Penetration of Electronic Data Interchange Across Industries [1,2]

Industry	Approximate Level of Penetration
1. Railroad	90%
2. Trucking	75%
3. Grocery	50%
4. Automobiles	35%
5. Retail	10%
6. Banking	5%

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1 Estimates based on Gartner Group Research

2 EDI Systems include public or private networks which support the generation, transmission, and reseption of standardized business forms such as invoices, purchase orders, etc.

characteristics of the inter-organizational field. In other words, we argue for a movement away from research studies that focus on a single focal organization for examining the nature of inter-organizational systems towards focusing on a system of organizations linked in multiplex ways, with a marked attention on the linkages enabled through information technologies.

We are disconcerted by the fact that for the most part existing research perspectives on the design and use of information systems within an organizational context are limited by their narrow conceptualization of an "organization" and its relevant "environment." We believe that this limitation stems mainly from (i) their general characterization of an organization in formal distributional (e.g. organization chart, division of responsibility, authority, etc.) and categorical (e.g centralized versus decentralized, mechanistic versus organic, differentiated versus integrated, etc.) terms as opposed to relational terms (i.e. actual interaction patterns based on both internal and external flows of goods, information, and authority) and; (ii) their abstraction of the environment as a source of undefined uncertainties (e.g. volatility, turbulence, resource scarcity, etc.) as opposed to a field of specific interacting organizations which locate the source of these contingencies (Aldrich and Whetten, 1981; Scott, 1983; DiMaggio, 1986).

Attempts to address these limitations in the broader stream of organization theory has seen the emergence of an analytical perspective that characterizes organizations in terms of the different patterns of relations embedded in an environmental field of other organizations. Labeled "network theory", this view contends that the structure of the overall network of interactions both constrains and liberates individual action, and in some situations may be more critical to consider than the isolated characteristics of a focal organization. It is our contention that this analytical perspective offers significant prospect of addressing some of the fundamental questions regarding

the creation of interorganizational information systems, though considerable research is required to advance both the theory underlying network analysis and its application to this stream of theoretical problems.

It is necessary, at the outset, to circumscribe the domain of this paper. We are interested in integrating relavant streams of information systems research (especially interorganization information systems) with relevant organization theoretic perspectives (especially network theory) to argue why further research efforts in this area should be grounded in a network orientation. Thus, we do not propose to review and classify the prevailing IT systems (those interested are referred to sources such as: Barrett and Konsynski, 1982; Cash and Konsynski, 1985). Nor do we focus on the technical details and capabilities of the different types of systems (readers are referred to Estrin, 1985). With a marked focus on interorganizational information systems from an organizational theory perspective, this paper is organized as follows:

Section I briefly traces the evolution in the research perspectives on the organizational context of information systems. We argue why interorganizational information systems need to be researched from a different perspective than the earlier research on information systems that were largely confined to the boundaries of a single organization (conceived in traditional terms).

Section II reviews the state-of-the-art in network analysis, which includes a discussion of (a) the conceptual steps involved in the analysis of networks, and (b) the nature of network data, the methods employed to study the different structural properties of networks as well as their application in different substantive areas. We attempt explicitly to show how these conceptual elements are appropriate and may be readily extended to the research context of interorganizational information systems.

In Section III, we discuss the power of this analytical approach by

raising specific theoretical and substantive questions relevant to the management of interorganizational information systems.

In Section IV, we outline the potential applications of the perspective developed in this paper for the CALS/ICS project.

Based on this discussion we conclude that the network perspective outlined in this paper is a very promising framework to explore in the context of interorganizational information systems.

I. RESEARCH ON THE ORGANIZATIONAL CONTEXT OF INFORMATION SYSTEMS

Research in information systems spans a variety of perspectives -- ranging from largely technical issues of system configuration such as hardware and software to strictly organizational issues such as the design and implementation of systems within and across organizations. In this section, we are primarily concerned with research on the organizational context of information systems. The purpose of this section is to provide a brief overview of the developments and shifts that have taken place within this stream of research to argue why a new research perspective is needed to address the organizational issues most germane to the management of interorganizational information systems.

The history of research in this stream can be divided into three stages for expository purposes. It is interesting and perhaps significant that these three stages roughly correspond to the three stages in the evolution of organization theory as classified by Scott (1983:155-160). Table 2 provides an overview of the three stages of research on the organizational context of information systems against the backdrop of the parallel evolutionary development of organization theory.

Stage One: Single-Task Information Systems Within a Single Organization

As a starting point, we consider the stream of research that

TABLE 2: EVOLUTION OF INFORMATION SYSTEMS RESEARCH

		Stage 1: Closed-Systems	Stage 2: Open-Systems	Stage 3: Network Systems
A.	DESCRIPTION	Information systems are designed and managed from the perspective of a focal task-unit of an organization, e.g. payroll, inventory control, etc.	Information systems are designed and managed to support more general organizational goals; formation of a distinct department/function to coordinate and manage the IT activities to support the corporate policy/strategy of the organization	Information systems are designed to extend across the boundaries of multiple organizations within a defined domain. Such systems imply different roles for the different participants in the network
B.	PARALLEL ORGANIZATION THEORY PERSPECTIVE	Closed-Systems Theory (March and Simon, 1958)	Open-Systems Theory (Galbraith, 1973; Tushman and Nadler, 1979; Daft and Lengel, 1986)	Networks or Field Theory (Laumann et al, 1978; Scott, 1983; DiMaggio, 1986)
C.	BASIC DISTINGUISHING ELEMENTS			
1.	Organization-Environment Link	Organization independent	Organization and environment technically interdependent	Breakdown of rigid organization-environment boundaries
2.	Characterization of Environment	Exogenous given - not considered seriously	Environment as a set of contingencies	Environment as an organizational field
3.	Focus of analysis	Organizational task-unit	Single focal organization	Organizational field of interlinked organizations
4.	Structural Properties of Interest	Span/Locus of control of information and resources	Degreee of differentiation vs integration in terms of centralization, formalization etc.	Relational and positional network attributes such as centrality, cohesiveness, equivalence, etc.
5.	Design Objectives	Minimize control and coordination failures; system efficiency; and individual satisfaction	"Fit" between information processing contingencies posed by the environment and organization structure. General system efficiency with regard overall organizational strategy	Variety generatinging and enhancing as opposed to contingency controlling; flexibility; capacity for change; etc

focuses on individual systems largely geared to achieve specific, structured tasks within an organizational sub-unit. Representative systems within this stream are: payroll accounting, inventory control, accounts payables, etc.

Research efforts in this tradition seek to understand how an IT system can best automate a specific data-intensive task environment within the organization. The assessment relies on criteria such as: user information satisfaction (e.g., Bailey and Pearson, 1983), system use (see, Ein-Dor and Segev, 1978), and system effectiveness in terms such as the increased control and reduction of failures.

A close parallel may be observed in the work of early organization theorists concerned with the role of communication in accomplishing various tasks in an organization. For instance, March and Simon (1958) viewed the structure of communication channels as being critical to the interdependence between decision points and points that generate data that an organization requires. Thus, several researchers (Bavelas, 1951; Guetzkow and Simon, 1955), working in laboratory settings, explored the efficacy of different types of communication channels for the performance of different tasks.

One can readily see the rationale for considering these parallel traditions of research a "closed system" view of information systems and organization theory respectively. In both, the systems are designed and researched with minimal attention to the broader organizational and environmental context. The approach to the design of systems is largely predicated on the objectives of the system's tasks and is considered to be fairly invariant across different organizations. Research efforts are largely aimed at the level of the individual and particular task to be carried out by them with the objective of designing systems that enhance both the overall task performance and the satisfaction of the individual.

Stage Two: Multiple Systems Within A Single Organization

The second stage is characterized by a movement away from viewing systems as devices for automating data-intensive tasks but as mechanisms and tools for handling the more general information contingencies that need to be addressed from effective decision-making in organizations. This period is marked by developments such as decision support systems (see for instance, Gorry and Scott-Morton, 1971; Keen and Scott-Morton, 1978) that enlarge the scope and role of information systems within an organization. In this view, given the complex interlinkages within modern corporations, the scope of most systems cannot be confined to well-defined structured tasks within a specific sub-unit, but have to interconnect multiple unstructured tasks within the organization. For a single business organization, such interlinkages are across functional spheres such as manufacturing, marketing, and finance and for a multi-business organizations, the interlinkages are across multiple businesses, and the level of interconnection is dictated by the extent of resource sharing and synergy across the businesses.

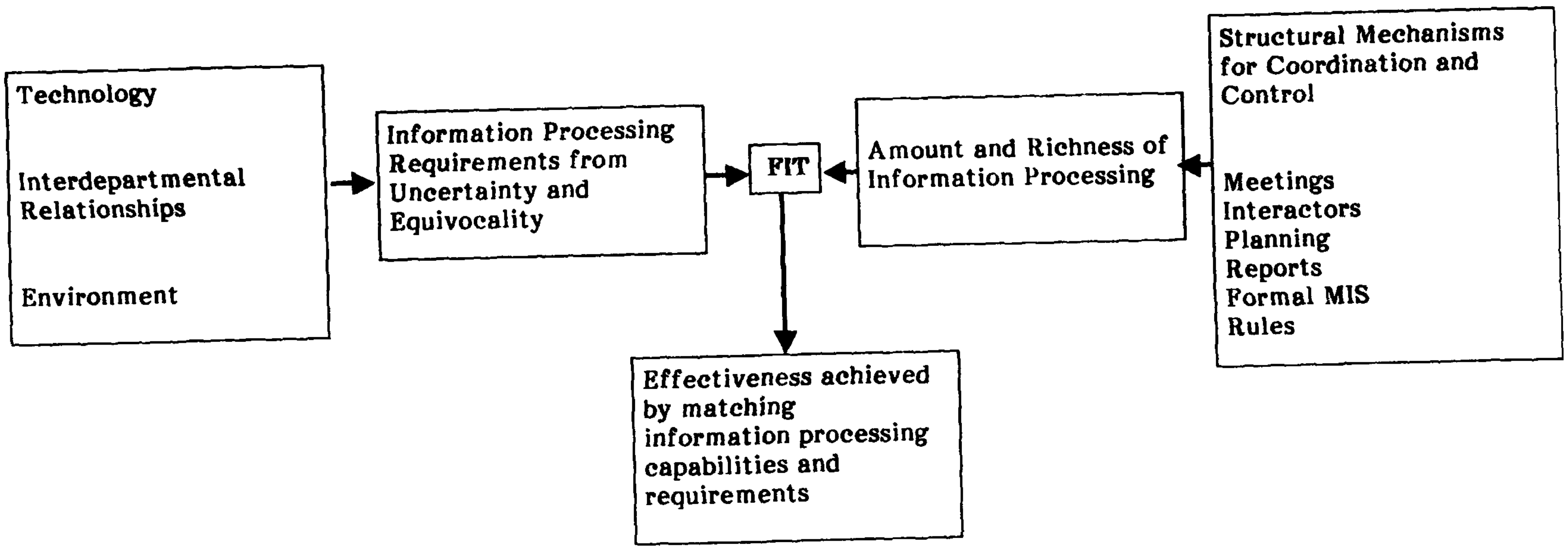
As a result of this enlarged view of information systems, the role of information systems increased in importance and gave rise to the creation of a separate function/department in most large organizations. This function had the responsibility to manage and coordinate the activities pertaining to the design and implementation of information systems. The overall configuration of the organization structure dictated the positioning of the information systems function as well as the level of centralization and decentralization of responsibilities and authorities for information systems activities. The focus of research shifted markedly from enhancing user information satisfaction and discrete system effectiveness towards the more general achievement of organizational goals through the management of critical information contingencies faced by the organization.

We call this stage of research an "open-system" view of information systems to highlight its close linkage with developments that are categorized under this label in organization theory. Prominent among these developments was Galbraith's (1973) attempt to move beyond the closed system view of organizations by extending the conception of communications to include "information processing" as a central organizational process. This set the stage for later researchers in the open-systems tradition such as Tushman and Nadler (1979) and Daft and Lengel (1986) to build on Galbraith and develop a descriptive model of how to match the information processing capacity of an organization with its information processing requirements. As shown in their summary model (see, Figure 1) Daft and Lengel suggest that the source of the information processing requirements are uncertainty in the task environment, as well as the amount of task interdependency. They then propose a range of structural mechanisms for coordination and control and organizational designs varying from mechanistic to organic that "fit" specific information processing requirements. One can readily see the how the logic behind the design of information systems outlined above corresponds closely to this research orientation.

Stage Three: Inter-organizational Information Systems

The third stage is characterized by a quantum shift in terms of linkages across multiple organizations in a marketplace. The point of departure from the second stage is provided by the configuration of systems that extend beyond a focal organization's traditionally-conceived boundaries to interconnect the information systems of key suppliers and customers. Termed as inter-organizational systems (IOS) or electronic data interchange (EDI), such systems have been argued to provide new sources of competitive advantages to those firms that have designed and deployed them (see for instance, Barrett and

Figure 1: Summary Model of Information Processing and Organization Design (Daft and Lengel, 1986)



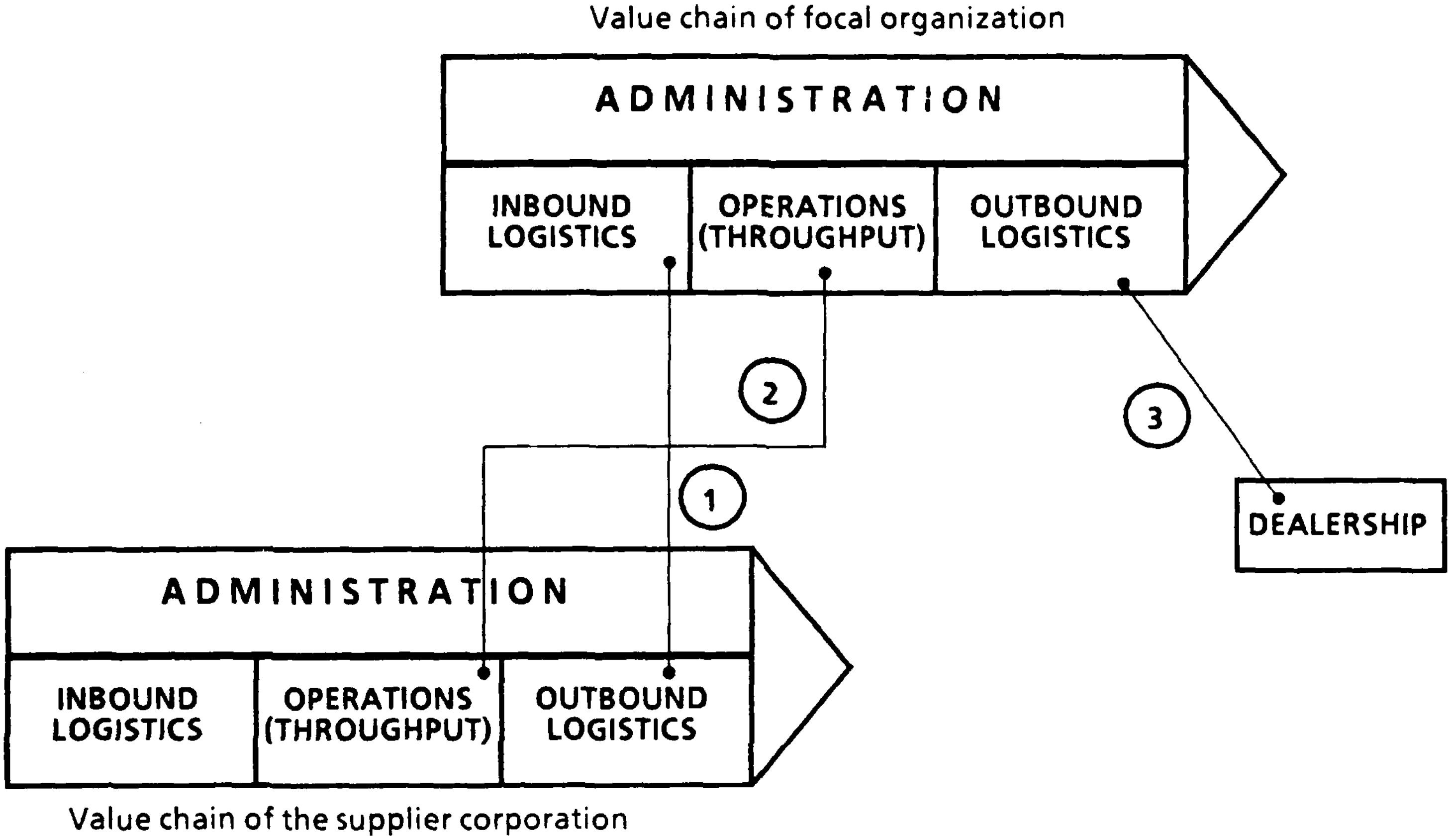
Konsynski, 1982; Cash and Konsynski, 1985; Keen, 1986).

In this context, the focus shifts from a single organization towards an 'organizational field' in which these interlinkages exist among the value chains of the various players that are connected. Figure 2 is a schematic representation of the interdependent value chains in an organizational field. If these interdependent value chains lie entirely (or, mostly) within the boundaries of a single organization, the design and implementation of such a system can be achieved through appropriate corporate-level policies. However, when such value chains extend beyond a single corporation, a major issue pertains to the possibility of differential benefits from the deployment of such systems. At one level, the benefits of such systems can be assessed from the viewpoint of the broader organizational field to post increased efficiency. At another level, there exists some potential for some organizations to realize and exploit firm-level advantages often at the expense of other participants in such information systems (see Cash and Konsynski, 1985).

However, it is important to recognize that research in this stream is at an infantile stage as compared to the other two stages of research discussed earlier. Indeed, it is significant to note that the results pertaining to the benefits from interorganizational systems have largely been anecdotal with little systematic research. More importantly, the attention has been on assessing the benefits accrued to a focal organization when deploying information-based links with their suppliers/customers.

What we are witnessing is a progressive shift from the second stage to the third stage in terms of the applications of information technology. Since the previous stages are conceptualized from the point of view of a focal task environment (in stage one), a focal organization (in stage two), it is not surprising that the conceptualization of the phenomenon in stage three is still wedded to the perspective of a single focal organization. However, our argument

Figure 2: A Schematic of Interdependent Value Chains Connected through Interorganizational Information Systems



1. Order-entry system with suppliers (placing orders, receiving invoices, delivery schedules, etc.)

2. Integrated manufacturing system (ensure consistency among design, engineering and manufacturing across multiple value chains across corporations' boundaries)

3. Order-entry system with buyers (sending invoice and inventory data, obtaining market information, etc.)

in this paper is that this stage represents a qualitatively different phenomenon in the conceptualization and understanding of the role of information systems in the marketplace and that we need to move away from a single-organization perspective towards an organization field (or, a network) perspective. This is because of the inherent weakness and the myopic vision that is characteristic of a focal-organization perspective as compared to the possibilities opened up by the netwok perspective. Indeed, "because interorganizational systems constitute a distinct logic type higher than that of single organizations, they require a theory and practice commensurate with that higher level," (Cummings, 1984:367).

Since the extant body of research on the network approach to the study of information systems is virtually non-existent, we have attempted to provide an overview of network analysis in the next section. Subsequently we address some of the questions that can be suitably researched from this perspective in a later section.

II: NETWORK ANALYSIS: A REVIEW OF THE STATE-OF-THE-ART

Network theory and analysis is not yet a single corpus of coherent knowledge.[2] Recently, however, the field has assumed a more coherent aspect with convergence around two professional journals - Connections and Social Networks and the publication of several excellent review articles (Laumann et al, 1978; Burt, 1980; Alba, 1982; Wellman, 1983). There seems widespread agreement, however, that there has yet to emerge a comprehensive theoretical model based on network thinking that may be used to guide research on organizational processes (Granovetter, 1979; Tichy et al, 1979). We organize our discussion of the basic issues under two headings -- principal concepts; and methods of analysis.

TABLE 3: CONCEPTUAL ELEMENTS IN THE ANALYSIS OF NETWORKS

ELEMENT	CRITERIA
1. Delimi' ..ion of a relevant organizational field	- Functional interdependence - Exchange/transactional interdependence - Relevant analytical boundary such as geography, industry etc.
2. Selection and definition of nodes	- Level of aggregation; individuals, groups, organizations, communities, nations, etc. - Distinguish between inter- and intra-organizational transactions - Distinguish between multiple roles and statuses
3. Type of Linkage	- Transactional; expressive, instrumental, cognitive or objective - Organizational interpenetration; joint membership, joint programs, joint ventures, etc.
4. Nature of Links	- Strength - Intensity - Symmetry - Reciprocity - Formalization - Standardization - Frequency - Loose vs Tight - Direct vs Indirect - Multiplexity
5. Modalities (cultural context) of network formation	- Normative context; competitive, contingent cooperation, or mandated cooperation
6. Historical context of network formation	- Place and time of network formation enter into explanations

Principal Concepts in Network Analysis

Most network analysts define a social network as a set of nodes (e.g. persons, organizations) linked by a set of social relationships (e.g. personal ties, transfer of information, overlapping membership) of a specified type. It is easy to see how in an information technology (IT) context, this definition may be enlarged to include IT-based links in addition to the economic and social links.

We elaborate and extend a review by Laumann et al (1978) to describe the different elements of the analytical enquiry entailed by this perspective (See Table 3).

1. Delimitation of a relevant organizational field: This involves choosing a criterion by which a particular set of actors is to be analytically treated as a bounded system of interaction. While this choice is often guided by the substantive problem at hand, the following four general criteria may be distinguished:

(i) A functional delimitation of the field -- that restricts the set to those that are functionally interdependent or share a common goal such as the social service delivery systems (Spergel, 1976) and employment service referral systems (Aldrich, 1976). Based on a similar logic, information systems researchers can limit the focus to interorganizational information systems within a particular marketplace such as the air-transport market or the financial services industry, taking care to include the various participants in the value-chain.

(ii) An exchange-based demarcation of the field -- based on identifying key transactions -- such that the delimitation reflects substantive transactions enabled through these systems and that the organizational members of the field who are potential partners in exchange transactions, because they control resources on which other

organizations in the system are dependent (Benson, 1975) -- e.g. national medical service systems.

(iii) Geographically defined organizational networks have been demarcated by neighborhoods, municipalities, metropolitan regions, district counties in a state, etc. (Laumann et al, 1978). While this criterion for delimiting an organizational field may have limited applicability in the interorganizational context in view of the capabilities possessed by new information technology to bridge geographically distant participants; it may still be applicable to those services that have a regional basis such as regional banking, telecommunications, transportation, movie theatres, etc.

(iv) An institutionalized domain such as the non-profit theatre sector (DiMaggio, 1986), or any sector (that may not be a conventional industry, may be a part of an industry, or may span several industries) whose domain is reasonably well understood. Interorganizational information networks in domains such as the armed forces may be delimited by such a rubric.

The deployment of inter-organizational information systems enlarges the scope of the relevant organizational field by virtue of possessing the technical capability to interact with an extensive set of organizations. This poses a problem in terms of the difficulty of delimitation, requiring the information systems researcher to carefully articulate the rationale adopted in the development of a specific boundary for study. More importantly, this very issue highlights the need to employ a perspective like network analysis to realistically portray and depict the system of interorganizational linkages.

2. Selection and Definition of Nodes; In a closed-system view of organizations, delineating organizational boundaries was a fairly straightforward matter; in open-system and network models of organization, the boundary

problem becomes more problematic. While one of the strengths of network models is their ability to bridge the micro-macro gap, the analyst still has to distinguish between intra- and inter-organizational transactions and determine the most useful unit of social aggregation. Thus, network researchers have studied individuals in an organization (Lincoln and Miller, 1979), large corporations in a community (Galaskiewicz, 1979), and even larger nodes such as district counties and nation states.

A second issue pertinent to node definition arises because any organization in the network may have multiple roles and statuses (Merton, 1957). For instance, organizations may be members of different information networks (e.g. a bank's participation in an interconnected network or a hotel's participation in multiple networks) and may have a different status in each in terms of level of participation such as remote I/O node, application processing node, multi-participant exchange node, network control node, or integrating network node (Barrett and Konsynski, 1982). Thus, the mere participation in a network provides only a partial picture, requiring one to distinguish among types of participation in defining a node.

The interorganizational information systems raises another set of issues in relation to the selection and definition of nodes that are different from the case of information systems that are confined to the boundaries of a single formal organization. One needs to differentiate between portions of the system that are internal to some organizations (e.g billing and invoicing in a reservation system) from those portions that are 'common' (e.g. parallel query processing) across all organizations within the organization field.

3. Type of linkage: Broadly speaking, one may distinguish between two general types of network relationships, those based on transactions or exchange and those based on the interpenetration of organizational boundaries.

Transactional networks can be categorized according to their

transactional content (Mitchell, 1969). Following Kadushin (1978), one can distinguish between network flows that are primarily expressive (affect), instrumental (power), cognitive (information), or objective (goods). In the context of interorganizational information systems, examples of transactional linkages include routine information such as purchase orders, invoices, bills, etc. or more critical information such as technical specifications and inventory levels between buyers and suppliers within a value chain.

Relationships involving boundary interpenetration fall along a continuum from common membership in a loose coalition (Warren 1967) that involves a minimal degree of overlap to joint ventures (Aiken and Hage, 1968) that involve complex interpenetrations. Membership on broad standards such as MAP or partnership in highly interactive design systems such as those between ICL and Fujitsu represent an analogous spectrum of interpenetration in interorganizational information systems. These imply significant differences in terms of exploitation of these systems for differential, firm-level advantages.

4. Nature of links: In any network, the links between the various nodes may vary along a number of dimensions. Different researchers have discussed such characteristics of linkages as:

(i) Strength - In social networks among individuals this has usually been used to distinguish between strong versus weak frienship ties (Granovetter, 1973) or between the relative power one actor has over the other in an exchange relationship (Emerson, 1962). More generally, though, this is a measure of the extent of transactional flows across a link such as the volume of different information and goods transactions.

(ii) Intensity - Related to strength, this notion is typified by the degree to which actors honor obligations or forego personal costs to carry out obligations (Mitchell, 1969). This construct may be useful to identify preferred transactional partners within a network and uncover

implicit or explicit hierarchies of exchange.

(iii) Symmetry - This refers to the extent to which the ties between the actors are the same in terms of the amount and kinds of resources that flow from each other. It is generally agreed that most ties are asymmetric in content and intensity (Emerson, 1962; Mayhew, 1971). For instance Shulman (1976) reports a study in which only 36% of those named as close friends and kin felt symmetrically close in return to the persons who had named them. This characteristic has important implications for organizational networks because not all pairs of linkages within a marketplace exhibit symmetric characteristics and measures of asymmetry may reflect the distribution of market power.

(iv) Reciprocity - While ties are rarely symmetric, they are usually reciprocated in a generalized way. For instance, while clients send resources to patrons, patrons usually send clients such resources as goods, information, or protection in order to maintain ties (Wellman, 1983). Evidence of such reciprocity has been described in the Japanese relational contracting network by Yoshino and Lifson (1986). For instance, while price information primarily flows from the subcontractors/suppliers to the producer who determines the market clearing price, the producer often contributes valuable technical and managerial assistance to its suppliers. Such links are often crucial to the stability of a network and deserve more attention.

(v) Formalization - Linkages may be very formal to the extent to which the relation is based on a strict contractual agreement (Aiken and Hage, 1968) or may rely upon informal norms. For instance, one could contrast the highly formalized system of linkages between the various vendors of hospital supplies and hospitals as participants in the American Hospital Supply Corporation's ASAP system with a less formal

case defined by a PC-based network that would link virtually multiple vendors with multiple suppliers directly.

(vi) Standardization - refers to extent to which the nature of the linkage has been codified and is unchanging either over time or across a number of different nodal pairs. It may be used, for instance, to distinguish between transactions based on a standardized pred-defined menu of selections versus more open-ended interactive systems.

(vii) Frequency - Transactions between organizations may be episodic or highly recurrent and can have a significant impact on issues such as the vulnerability of the partners to opportunistic self-interested behavior by the other (Williamson, 1975). This property of links is useful, therefore, in understanding patterns of vertical and horizontal integration in a value chain.

(viii) Loose versus Tight Coupling - This distinction, though difficult to operationalize, has gained great popularity since a seminal paper by Weick (1976). Loose coupling is intended to convey the image of elements that are responsive to each other but retain their own identity as well as physical and logical separateness. The contrast between the American Hospital Supply system versus the PC-based system described earlier may also be used to distinguish between a tightly versus loosely coupled system.

(ix) Direct versus indirect - While most linkages considered till now describe the nature of a direct linkage between the two actors in a social network, at times it maybe useful to consider indirect linkages as opposed to direct linkages as when a broker mediates between a buyer and a seller.

(x) Multiplexity - It is important to recognize that nodes may be linked by multiple relations (Barnes, 1972). This is particularly important to

emphasize in the context of an interorganizational information systems network to highlight the immanence and simultaneity of social and IT-based links.

Our brief review has highlighted several aspects of linkages that would be critical to an in-depth analysis of a network. Yet little rigorous analysis sensitive to these aspects of relationships has been undertaken even in the broader stream of organizational theory, as most of the existing procedures of network analysis can only handle data in a binary code indicating the presence or absence of a linkage (Burt, 1980). Increasingly though, procedures are being devised for handling dimensionalized links.

5. Modalities of Network Formations: To this point we have focused on the elementary components of network structure - nodes and linkages. Next, we shift our attention to the level of the total network and consider those aspects of the overall context that influence the pattern and texture of interorganizational networks.

The notion of an institutional context permeating an interorganizational field is drawing increasing attention in the literature (Scott, 1983; DiMaggio and Powell, 1983). Also referred to as "modalities" these contextual conditions are seen to define the norms of legitimate organizational behavior in transactions (Laumann et al, 1978). Included in the notion of modalities are "normative systems" that attempt to define the rights and relations of the organizational members and "meaning systems" that are employed to define and interpret actions within a field (Scott, 1983).

For instance, Scott (1983) proposed that interorganizational fields vary in terms of whether they contain a "bureaucractic" or a "professional" soverign. In some arenas a centralized, bureaucratic system exists that provides a framework within which work is performed whereas by contrast professional arenas are organized in a decentralized fashion, the dominant profession

collectively supplying an ideology that structures and legitimates work in the area while reserving specific applications of governing principles to individual practitioners.

At a more general level, Laumann et al (1978) have distinguished between "competitive" and "cooperative" modalities. The competitive modality of network formation involves norms much like those surrounding firms in a perfectly competitive economic market. A cooperative mode implies very different expectations. The implicit assumption is that total welfare will be maximal when organizations with partially differentiated goals consciously cooperate to attain a collective purpose for which the interorganizational field has responsibility.

A brief example illustrates the importance of this overall network modality in the context of interorganizational information systems. There was a time in the airline industry when the availability, display and use of the information flow on the reservation system to the consumer, agent, and airlines was dictated by the design of the system. This helped the individual airlines that controlled or owned the different systems to decide on pricing and promotion as well as to introduce a positive bias in the display of route structure on the system. In this situation, there was clearly a potential of the abuse of monopoly power that derived from the control of critical information. Since that time, however, the modality of the network context has been altered completely by the regulations imposed on the use of information by the Civil Aeronautics Board. The reservation system now is much more "competitive" and "egalitarian" in contrast to its earlier "oligopolistic" and "hierarchical" modality.

6. Historical Context: Another aspect of network formation that is often ignored is the historical context of network formation. An analysis is historical to the extent that the time and place of the action enter into its expectations. Given this view, while longitudinal studies are desirable, to call

for a historical perspective, is not to insist on such designs but to emphasize that all system elements - nodes, relations, beliefs should be understood as having a time subscript. For instance, this alerts the analyst to arguments such as Stinchcombe's (1965), that organizations are "imprinted" by the forces present at the time of their creation - an insight that has powerful explanatory power in understanding patterns of relations in such emerging industries as biotechnology and financial services. The airline industry example described above also attests to the importance of this view.

Methods of Network Analysis, Structural Properties of Networks and their Substantive Applications

The analytic perspective outlined above lends itself equally to qualitative and quantitative research methods. Much of the early network research was qualitative in nature, but since then there has been a proliferation of highly sophisticated quantitative methods for deriving the structural properties of networks. While this development has been criticized by some researchers (Fombrun, 1982) for giving network research an overly "techniques" aura that obscures its potential contributions to organization theory, it also holds great promise because it offers a useful complement to current multivariate analysis by adding a specifically relational dimension to the existing distributional data.

We examine next some of the more important quantitative methods of network analysis and the structural properties of networks derived from them (for more detailed reviews, see Burt, 1980; Rice and Richards, 1985). We also discuss some substantive applications of these network properties.

Network Data: The substrate or raw data on which network analysts typically work are matrices in which each cell represents a specific type of link from one network member to another. Multiple matrices are used

TABLE 4: STRUCTURAL PROPERTIES OF NETWORKS

STRUCTURAL PROPERTY	EXPLANATION
A. Overall Network	
1. Size	Number of individuals participating in the network
2. Density	The ratio of potential ties to actual ties
3. Connectivity	The degreee to which members of the network are linked to one another through direct or indirect ties. (A maximally dense network is fully connected but full connectivity is also compatible with low density)
4. Clustering	The number of dense regions in a network
5. Hierarchy	Degree to which members direct unreciprocated ties to other members
6. Reachability	Average number of links between any two individuals in the network
B. Network Partitions	
1. Cohesiveness	Partitions of networks that interact maximaliy with each other and minimally with others
2. Equivalence	Organizations in each partition share similar relations with organizations in other blocks whether or not they are connected to each other
C. Nodes	
1. Liasons	Nodes with maximal interaction with members of other groups or liasons, but not with any particular group.
2. Bridges	Group members who are linked to other groups directly.
3. Gatekeepers	Group members who serve as interface with non-group members
4. Isolates	Nodes that have the least number of links with other members of the network
5. Centrality as measure of activity	Total direct nominations in a network
6. Centrality as measure of betweeneness	Nominations in pathways of connectivity
7. Centrality as measure of closeness	Distance from different clusters

to describe networks that have several types of links among members: the analysis may then focus on a specific aspect of the structure in these multiple networks or consider combinations of some or all of the different types of links jointly. While network analysts strive for complete relational data on some analytically defined field of actors, a "snowball" sampling technique has also been used for larger systems (Granovetter, 1976; Erickson, 1978). Most of the present network methods use binary data in the matrices, indicating the presence or absence of a tie, though attempts have been made to incorporate a metric of the links such as their intensity or degree of interpenetration (Burt, 1976; Winship, 1976).

Network Methodologies: Three sets of network methodologies can be distinguished depending on whether they (i) describe structural properties of the overall network, or (ii) decompose the network into partitions or (iii) decompose the network into its individual nodes (for a summary of the different structural properties at each level, see Table 4).

A. Overall Network: Starting with the early network analysts, matrix algebra has been used to compute structural properties such as density - the ratio of actual ties to potential ties in a network, and reachability - the average number of links between any two nodes in the network. Such simple properties were found to be very useful in understanding such phenomena as the diffusion of medical innovations (Coleman et al, 1966) and the functioning of labor markets for professional jobs in an urban community (Granovetter, 1974).

In a separate stream of research, communication theorists (Bavelas, 1951) were concerned with overall network properties such as connectivity - the degree to which members of the network are linked through direct and indirect ties, allowing one to distinguish between dense networks in which most members are connected versus sparse networks in which few members have links.

Another extremely important set of methods are relational graph theoretic methods developed by Coleman (1964) to study the extent of stratification in the overall network structure. The most important structural property is hierarchy - the degree to which members direct unreciprocated ties to other members. This property has been shown to have a significanct impact on outcomes of collective decision making and has helped understanding systematic biases in such situations (Coleman, 1966).

Finally, spatial analysis methods have been used to represent the entire network in a two or n-dimensional space to visualize graphically the overall structure of the network and arrive at loose specifications of clusters and how these might affect substantive issues such as the diffusion of a major innovation in the steel industry (Czepiel, 1975).

B. Network Partitions: The primary concern of network analysts is the identification of network partitions based on one of two criteria: (i) positional - organizations belonging to the *partition* exhibit similar patterns of relation with other members in the network but not necessarily among themselves; or (ii) relational - members of the partition that share strong relations with each other but not with other members in the network (Burt, 1978a).

Based on this distinction network methodologies have used clustering techniques (Arabie, 1977; Bailey, 1974) multidimensional scaling (Caroll and Arabie, 1980; Kruskal and Wish, 1978) and graph-theoretic methods (Atkin, 1974; Cartwright and Harary, 1977; Seidman, 1979) to identify network partitions of organizations that interact maximally with each other and minimally with others. Studies of network partitions based on cohesiveness have been used to study elites in an invisible college (Crane, 1972; Breiger, 1976; Burt, 1978b) and the impact of political elites in a community (Laumann and Marsden, 1979).

Another set of network methodologies has focussed on positional

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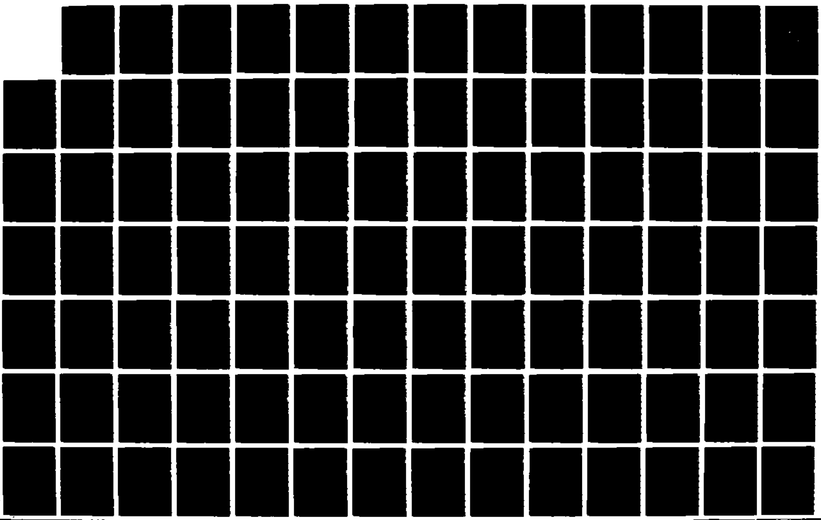

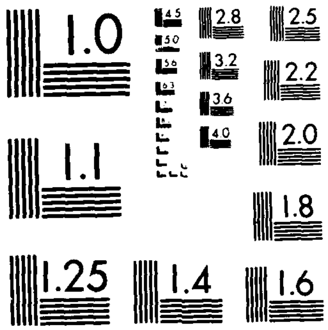

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network features such as structural equivalence or relatedness. The techniques include factor analysis (Bonacich, 1972) and a family of blockmodelling algorithms (White, Boorman, and Breiger, 1976; Boorman and White, 1976; Burt, 1976; Sailer, 1978). This approach represents perhaps the most exciting development in network methodology as it provides empirically derived characterizations of such powerful theoretical concepts as network "role" based on relational information. Substantive applications of blockmodelling such as studies of member cognition in an electronic network (Walker, 1985), and end-usage patterns of electronic media in organizations (McKinney, 1985), demonstrate the potential of this approach at the individual level and offer encouragement for its application at the interorganizational level.

C. Nodal Properties: These methods involve the decomoposition of the network into its nodal properties based on information of the overall pattern of network linkages. The most prominent methods are linkage based pattern recognition algorithms such as NEGOPY (Rice, 1978; Wigand, 1979) which maybe used to identify nodes as (i) liasons - or network actors that have most of their interactions with members of different groups or with other liasons, but not with the members of any single group; (ii) bridges - group members who are linked other groups directly; (iii) gatekeepers - group members who serve as an interface for interactions with non-group members; and (iv) isolates - network members who have the least number of links with other members of the network.

Another prominent nodal property is centrality derived from graph theoretic methods (Freeman, 1979). Three types of centrality may be distinguished based on (i) activity - which is a measure of the extent to which a node dominates the volume of network activity; (ii) betweenness - which is a measure of the the number of nominations of a node in pathways that establish connectivity and is important in terms of the node's control over the network

activity; and (iii) closeness - which is a measure of short links that emanate from a node and is important in terms of the node's efficiency in directing network activity.

With this, we have completed our review of the basic elements of network theory. We have attempted in the process to motivate our contention that this analytical framework holds great promise for research on interorganizational information systems. We turn next to a more systematic discussion of the research implications of this perspective.

III. IMPLICATIONS FOR RESEARCH ON ELECTRONIC INTERORGANIZATIONAL NETWORKS

While the emergence of inter-organizational information systems has opened up a Pandora's box of potential applications that could revolutionize the landscape of economic organization, it has also opened a can of theoretical and substantive problems that need to be better understood if its promise is to be fully realized.

For the information technology theorist and designer, the set of possible interorganizational system applications needs to be circumscribed not only by the resolution of the technical bottlenecks, but by the recognition that the information system will be embedded in a web of social relations that span the micro-macro spectrum from individuals to multiple organizations. For the organization theorist, the links fashioned by the technology are no less problematic as they open up a whole range of completely novel interactions among organizations involving systems that transcend conventional organizational boundaries and challenge most of the existing conceptions of organizations and their environments. It is our view that the network perspective outlined earlier in this paper is a framework of enquiry that bridges these concerns of the information technology and organization theorist in a powerful way.

Network analysis offers a more realistic conceptualization of organizational structure in such a diffuse organizational context. By viewing social structure as a continuously branching network of compound relations, and focusing on relations as the unit of analysis, fuzzy organizational boundaries are less problematic. Furthermore, network analysis allows for an examination of network structure based on technological and social links. Affect, authority, resource, and information flows can be considered singly or in any combination. This permits us to see for which particular activity the IT system has the greatest effect. It also affords a concrete assessment of whether the IT system is embedded in or is at odds with the existing social organization. By conducting network studies that examine structural changes over time, one might also be able to arrive at a much richer understanding of the complex dynamics and evolution of interacting information and social systems.

The potential insights to be gained by this perspective may be organized and discussed in greater in detail under the rubric of the following four sets of questions:

1. **Does the interorganizational information system alter the relevant organizational field? For which types of activities? Over what time frame?**

Network theory involves the breakdown of rigid organization-environment boundaries and the recognition that the environment is not merely a black box of abstract contingencies but a field of interacting organizations. Within this perspective, then, the growing number of electronic linkages among markets such as: airlines, travel agents, hotels, rental car agencies, tourist lines, etc. may be readily understood as being part of a functionally interdependent field. Thus, the demarcation of market boundaries is getting increasingly blurred. Similarly, analyzing the various interdependencies among the organizations involved in the field of tax preparation services may alert the researcher to the set of potential participants (such as tax preparers,

consultants, financial services companies, software manufactures etc.) in the as yet nascent interorganizational information system given the opportunities opened up by the decision of the Internal Revenue Service to accept electronic filing of tax returns.

While recognizing the scope of the potential network of functional, resource, or locational interdependecies among organizations liberates the researcher from myopic definitions of the relevant organizational field, attention to the content of the links prevents the researcher from the fallacy of conceptualizing the world as an electronically linked village. As mentioned earlier, the network perspective emphasizes that social and information content is often intertwined in interorganizational links. This warns against the design of systems based on a rationale of information interdependency that lead to a disjuncture with the network of social relations. For instance, it helps to explain why, in the industrial district of Prato, Italy, the attempts by ENEA (an Italian public agency) to supplant the flows of information transfer which relied heavily on face-to-face contact, the transfer of social cues, and social information, with the electronic transfer of information met with very little success (Scarpitti, 1987). More generally, this suggests that interdependecies or activities that rely on a low social content and high information content are perhaps most suitable for electronic organization.

At the level of the total organizational field, a network perspective may also yield specific insights regarding the evolution of an interorganizational information system. For instance, notions such as "critical mass" (Singh, 1987) may be operationalized more meaningfully by observing patterns of network connectivity in the potential organizational field and precisely locating the electronic links that need to be established to achieve the desired level of network linkage that would propel self-sustaining growth.

2. Does the interorganizational information system affect the pattern

of interactions and linkages? Does it change roles and statuses? For which types of activities? Over what time frame?

Several researchers adopting a network analytic procedure have shown that electronic organization can significantly affect the existing patterns of interaction among individuals in an organization (McKenney, 1985; Walker, 1985). Singh's (1987) case study of the electronic organization of the over-the-counter (OTC) securities market by NASDAQ (National Association of Securities Dealers Automatic Quotes) provides compelling evidence that this conclusion is also true at the interorganizational level. Until the 1960's, the OTC market was a sprawling and disorganized network of traders and brokers who relied on a complex pattern of socially mediated information exchange to accomplish daily transactions. Increasing complaints about broker-dealer inefficiency led the SEC to charge NASD with the responsibility of exploiting information technology to improve the efficiency of the market. Starting with a 20,000 mile leased line network in 1971, NASDAQ has evolved into a system on which nearly 1600 companies have their 2,505 securities exposed to the market, making NASDAQ among the largest securities markets in the world. Indeed, the transformation of the patterns of security trading induced by NASDAQ led MCI chairman Bill McGowan to remark - "If someone suggested building a new stock exchange today by setting up a corral in the most expensive strip of land in the country today, they'd be considered daft, because they'd be ignoring everything that has developed in the last hundred years. [..] In NASDAQ, we see the prototype of a future global stock market in which the investors can trade at any time from any location through a computerized communication system. [It is] a market that combines continuous trade reporting and competing dealers, a market built around technology and not just accomodating it, a market unlimited in time and space, and not tied to a single physical location." (quoted in Singh, 1987, p.50-51).

Network analysis can help understand better the dramatic changes

in the roles and status of individual organizations wrought by an interorganizational information system. This finding has significant political implications -- the alteration of the centrality or political influence of important stakeholders might lead to perverse outcomes such as resistance to the implementation of the IT system, or even attempts to circumvent/sabotage the IT system to regain power. Network analysis can help identify such central actors beforehand and thus suggest a strategy of cooptation that could prevent such perverse outcomes. For instance, in the NASDAQ case, a reduction in centrality may be used to reflect the change in status and role of the small set of brokers central to previous socially organized market. At the same time, techniques such as blockmodelling may be used to reveal sets of traders or brokers who have similar trading patterns in the network and may be used to monitor potential cliques of insider-trading.

Network analysis may also be used to understand the sources of competitive advantage enjoyed by different members in the network and in the identification of strategic groups based on relational patterns (Nohria, 1987).

As described earlier, the limited success achieved by ENEA in altering the patterns of interaction in the industrial district of Prato, highlights another important analytic insight of the network perspective. By calling attention to the content of linkages in a network, this perspective forces the researcher/analyst to evaluate the potential tension between the IT-based and socially-based links. Ignoring this tension can lead to unsuccessful implementations as suggested by Singh's (1987) analysis of McGraw-Hill/Citibank's GEMCO as a counterpoint to the phenomenal success of NASDAQ. He concluded that the limited success of GEMCO was not due to a technology failure but could largely be attributed to its having ignored the critical role of socially determined reputational links in designing an electronic market for oil.

By studying structural changes over time network analysis may

also yield insights about the dynamics of role changes and further examination of such poorly understood theoretic concepts as mobility within and across strategic groups (Caves and Porter, 1977).

3. Does the interorganizational information system affect the control and coordination patterns? For which types of activities? Over what time frame?

In answering this set of questions, adopting a network perspective reveals perhaps the most serious lacunae in our present theories.

An interorganizational information system involves investments in capital equipment and shared systems/software that transcend conventional organizational boundaries. This seriously challenges classical conceptions of organizations as it raises such fundamental questions as -- what is an organization? If coordination and information flows are to occur across organizational boundaries, what is the core set of activities and organizational routines that define an organization?

A related set of basic theoretical questions within the domain of agency theory (see, Pratt and Zeckhauser, 1985, for an accessible review of this literature) is posed by the recognition that an interorganizational information system fundamentally alters the distribution of information in a network of principal-agent relationships. Since the structure of information asymmetries between the principal and agent is the major explanatory variable of forms of control and governance in agency theory, these electronically induced changes pose thorny theoretical probelms.

In practical terms these theoretical concerns translates into such questions as -- what is the appropriate structure and control system in a form of organization where control of physical and informational assets by virtue of sole ownership and unambiguous property rights is no longer an adequate basis for decisions? For example, does a participating bank have access to the vital

information on "customer use patterns" in all portions of the automatic teller network or only to a select segment? At what level is the data proprietary in a network such as NYCE, in which many of the participants are also competitors in different product-market sectors?

4. Does the interorganizational information system affect the effectiveness/efficiency/flexibility of the system? For whom and which type of activities is the impact most salient? Over what time frame?

The benefits to be gained by the implementation of an interorganizational information system are legion. Singh (1987) documents the phenomenal success of systems such as NASDAQ, SCENE - a computer exchange network, TRANSNET - an automotive market, and the electronic auction of livestock and agricultural products. Barrett and Konsysnski (1982) describe many examples of network efficiencies such as cost reductions per transaction, network effectiveness such enhanced productivity accomplished by fewer redundant and more direct transactions, and system flexibilities such as the organic evolution of systems to incorporate a growing range of transactions and an increasing set of members. While, a network perspective allows for a more precise explanation of these benefits grounded in the structure of the network, it also explains failures such as the cases of ENEA in Prato and GEMCO in oil markets by forcing an examination of the social and informational content of the network links.

Network analysis allows benefits to be measured at a system level in addition to the individual actor level. This micro-macro bridge can be extremely useful in identifying bottlenecks in an overall system. Network researchers (e.g. Kmetz, 1984) have highlighted that individual effectiveness does not translate into overall effectiveness without system integration across multiple dimensions. By focussing on the patterns of linkages among network actors, such as connectivity and reachability, network analysis could provide a

much sharper insight into the source of such critical system level failures.

One of the great promises of IT is the flexibility it affords in organizational design. However, it is important to recognize that the IT system might actually lead to a rigidity in structure as it embedds interaction patterns in relatively fixed action routines and immovable electronic equipment. Studying network structure over time can help understand this flexibility dilemma more systematically. This is clearly a dimension of vital interest to researchers in terms of understanding the time horizon over which any interorganizational information system is strategically and organizationally viable and effective.

IV. POTENTIAL ROLE OF THE NETWORK PERSPECTIVE IN THE CALS/IDS PROJECT

In this section, we briefly illustrate the potential role of the network perspective in the context of the CALS/IDS project. It is important to recognize that this discussion is intended to be illustrative rather than conclusive as we have not yet conducted any serious research in this particular context at this stage.

Increasing Trend towards Interdependent Value Chains

In cases of inter-dependencies across multiple value chain, the traditional frameworks for organizational analysis are inadequate since they require treating individual organizations as isolated, free-standing entities. The network perspective is useful to conceptualize such situations. For example, when a major aerospace company requires that its major suppliers acquire computer-aided design equipment that is capable of direct linkage with its CAD installation, the two value chains are inter-twined and traditional organizational analysis is of limited value.

This is also evident in the USAF context. Consider the proposed

system for the computerization of technical orders such that updated information is readily available at various parts of the organizational chain. When these interdependent value chains transcend across multiple organizations such as Rockwell, and other subcontractors, it is quite difficult to manage and control these networks/systems using policy directives. This is because of the real possibility that exists for exploiting differential firm-level benefits from such a system. So, while one could argue that such systems reduce overall inefficiency, such a notion fails to reflect the need and self-interested motivation of different players to protect and exploit firm-level information for competitive gains in the market.

Given the inevitable trend towards such interconnected value chains, the description of such systems is best carried out from a network perspective. As described earlier in this paper, a network perspective could provide useful indicators such as the degree of connectivity in the network, the centrality of different members of the network, and in identifying groups of members who have dense information and transaction linkages among them (cohesiveness), and those that have similar linkages with others though not necessarily links with each other (equivalence).

Balancing "Cooperative" Versus "Competitive" Roles

A logical corollary to the issue of interdependent value chains is the recognition of the existence of two, sometimes conflicting, roles -- competitive versus cooperative -- for the major players. Let us consider the following scenario:

> A B-1B bomber flying in the European sector develops an operational problem. Although it is able to land safely at its base, it is determined that the problem is potentially serious. The overseas base informs Dyess Air Force base, which in turn alerts the 15th Air Force, SAC Headquarters, Tinker Air Force Base, and the Rockwell International Support Control Center. Rockwell in turn contacts one or more of its subcontractors depending on the nature of the problem. Each of these subcontractors generates and stores technical data in digital format. However, currently the air force receives weapon system technical information on paper and microfilm. This causes the B-1B bomber to

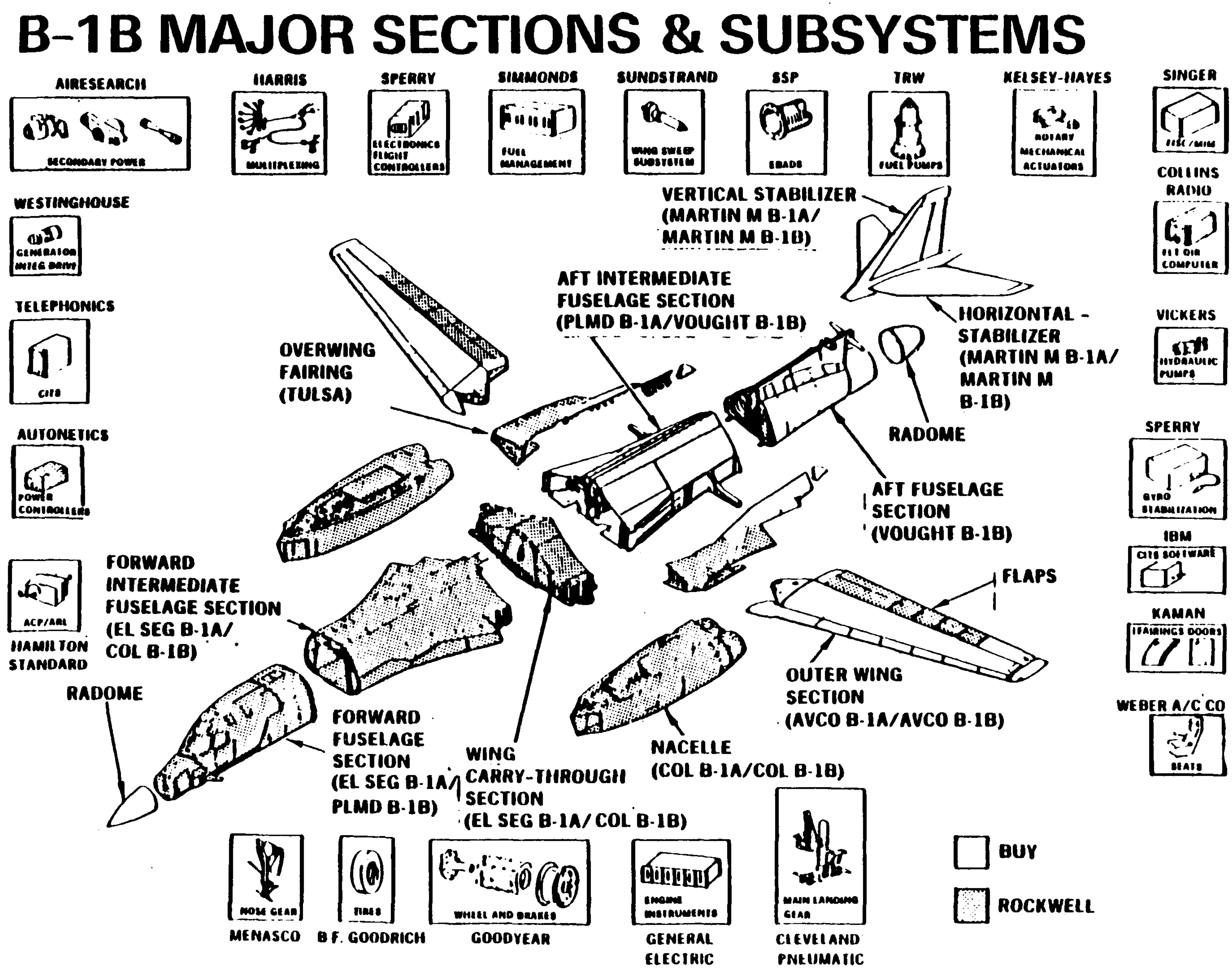
> remain un-operational until the relevant pieces of technical information can be identified, retrieved, consolidated and studied. Only then can a combined Engineer/Manufacturing/Logistics effort be established to develop a field repair procedure.

It is very difficult to put a price tag on the opportunity cost implicit in the delay in repairing the aircraft. The cost will obviously be higher in war time than at peace time. It is clear that an accelerated pace of aircraft repair involves quick and efficient retrieval of information stored in different computers at geographically dispersed sites.

The organizational issues involved in accomplishing this information exchange are complex. Rockwell Aerospace is the primary contractor, while there are several secondary contractors, and numerous other smaller contractors (see Figure 3). Their roles can be understood in terms of interdependent value chains. In this scenario, one can argue that the design and implementation of inter-organizational systems (such as the CALS project) is likely to improve the transactional efficiency of the overall network of relationships. The USAF, the primary contractor, the secondary contractors and others are all likely to agree that the system efficiency would be improved. As indicated earlier, the relative cost-benefits are well known, although the exact magnitude may vary depending on the context. Research studies (in the private sector) on the benefits of interorganizational networks among vertically interdependent players have consistently reported cost savings. This illustrates the "cooperation roles" of the participants, since there is general consensus that these systems are mutually-beneficial.

Simultaneously, though, these systems raise more a complex issue. This arises because the interdependencies among the network members are not constant. Any focal corporation can potentially integrate backwards and/or the supplying corporation can potentially integrate forward. These pose competitive conditions which may limit the scope of interorganizational systems and restrict the degree of information interchange.

Figure 3: Inter-Organizational Network for the B1-B Bomber



This issue is even more complicated in the CALS project. While the various types of contractors are likely to cooperate for the purpose of sharing the information that leads to improved operational efficiency, there exist serious concerns regarding the "proprietary" nature of the data. The specific issues are:

(a) The large set of corporations participating in a project like the B-1B bomber project have to collaborate when their activities are interdependent for one project, and as well have to compete among one another for other projects in the broader marketplace. Thus, each participant is unlikely to view its participation in one project in isolation of the competitive positions in the broader marketplace. Thus, a critical understanding of the relative balance between the cooperative and competitive roles is necessary for the effective design and implementation of any heterogeneous data systems that cut across the multiple corporations.

(b) The possibility that the information necessary to improve operational, transactional efficiency, may also be sources of competitive advantage for some of the players. Thus, different corporations may consider different types of information to be proprietary (reflecting their unique corporate strategy perspective), thus restricting the overall scope and design of the system. However, since the strategies of different corporations are generally different, there is a strong likelihood of some cooperation. Indeed, this understanding of the level and nature of cooperation among the actors/players in a network is critical for optimal system design.

Assignment of the Coordinating Role and Ownership of Data

The third issue pertains to the assignment of the coordinating role. This is because of its direct implications for the ownership of data. In the

private sector context, the ownership issue is typically approached as a point of negotiation among the concerned participants in the network, while the coordinator is usually the corporation that initiates the design and deployment of the network. It is expected that the perceptions of the different participants regarding the design of an interorganizational network will be critically dependent on the assignment of responsibility for coordination. However, this issue has not been researched, even in the private sector.

In the context of the USAF, the most obvious solution is that the USAF coordinates the network and owns the data. But, the primary contractor has such as central role in the project that it renders the separation of the access privileges between the primary contractor and the USAF very difficult.

A research issue emerging from the above discussion is: Given (a) the sensitive nature of data interchange, and (b) the overlap of cooperative and competitive roles, what is the impact on the key parameters of the system across different assignments of coordinating role and alternative modes for data ownership?

Prospects Offered by a Network Perspective

The attractiveness of a network approach to the study of interorganizational information systems lies in its ability to describe the structural properties of the emergent networks in terms of relatively simple characteristics such as:

(a) density (the ratio of actual ties to potential ties in a network); and

(b) reachability (the average number of links between any two units within the network).

We believe that the interrelationships among a set of participants in a market (not all of them competing against each other) can be best described using the principles of network analysis. Such an approach elevates the level of analysis of information systems research from the traditional single organization

perspective towards a more relevant level of analysis, namely an "interorganizational network."

A useful set of research questions that can be suitably addressed from a research perspective is:

(a) What are the key differences (defined in terms of network properties) among interorganizational systems across product markets?

(b) What are the theoretical reasons for the observed differences, in the pattern of networks?

(c) What are the implications (such as distribution of power and influence, and competitive advantages of different members) of differences in the pattern of networks?

(d) To what extent are the changes in the network patterns attributable to the recent trends in the cost-performance of information technologies?

We believe that these questions, among others, are of central importance to the success of the CALS/IDS project. A more careful elaboration of the relevant research issues, however, can only be accomplished after a closer examination of the details of the context.

CONCLUSIONS

We have shown the immense potential of network analysis in answering some of the critical questions posed by the introduction of an interorganizational IT system. We must admit, however, that the present state-of-the-art in network analysis does not allow us to answer them or to make predictions with any measure of confidence. This inability derives from both the lack of a coherent network theory as well as a shortage of substantive empirical work involving multiple organizations as focus of enquiry. Also, network analysis in which IT figures prominently is still in its early infancy

though several researchers are pursuing it vigorously.

A significant research effort is required before the promises and pitfalls of both IT and network analysis are better understood. We do, however, commend this research strongly, for as discussed in this paper, our present analytical tools are not going to get us very far. We are presently working on initial attempts at demonstrating the power and potential of network analysis to understand the competitive issues induced by IT in the market for tax preparation services -- where several different markets (traditionally conceived) are intersecting to change the complexity of competition.

ENDNOTES

1. For a discussion of the markets versus hierarchies paradigm see, Williamson (1975, 1986).

2. As suggested by Tichy et al (1979) its conceptual origins can be traced to the Simmelian (1950) emphasis on patterns of interaction and communication in sociology, the structural-functional approach in anthropology (Malinowski, 1922; Radcliffe-Brown, 1940) and role theory (Katz and Kahn, 1966) which defined organizations as "fish-nets," or "semilattices" (Friedell, 1967), of interrelated offices).

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THE USE OF STANDARD DATA DEFINITIONS IN COMPOSITE INFORMATION SYSTEMS

ANDREW TRICE

It is a fact that by establishing common standards for data definition, many organizations have accomplished significant improvements in the level of system development productivity, the quality of data, and the amount of coordination between organizations sub-units. However, it is not clear how these standards can be implemented in an interorganizational network setting, or whether these standards are always desirable.

If an organization builds a complete data model and standardizes every data definition in the model across the entire company, a total re-engineering of the firm's data infrastructure would be required. The benefits would be in terms of better coordination, higher level of efficiency, and a greater ability to handle new requirements. However, a complete standardization of data definitions is a very difficult task for several reasons. First, reaching a consensus on proper data definitions is not easy. Second, building a total data model is time consuming and expensive. Third, changing parameters will make the model obsolete even before it is implemented.

At the other extreme, the organization could leave the data of each unit intact and build "bridges" which perform all the necessary semantic mapping between a local unit's view of data and its interpretation by the rest of the organization. This approach preserves the autonomy of the individual units, and is less costly than the previous one. However, semantic mapping is not an easy task, and also the meanings change over time.

In between the two extremes, there is the option of Focused Standards, which could be characterized as a "Critical Success Factors" approach to data standardization. The attempt is to establish standard data definitions only for those entities which are both critical and stable. By critical, one means they are vital to the operations of the organizations. By stable, the connotation is that changes are relatively infrequent over time.

In this report, two decentralized companies that have adopted this intermediate approach are studied. In both cases the focused standards approach seems to be well-received. Four conditions for success were found: (1) initial narrow scope, (2) clear objectives, (3) self-interestedness, (4) line support--minimal but adequate (largely due to self-interest).

Looking to the future, four factors need to be researched further: (1) an organization's capacity for change, (2) the tendency to centralize control, (3) delays due to incremental approach, and (4) data access and control.

TECHNICAL REPORT #19

I. Introduction

As information technology is being used to perform or support an ever-increasing proportion of the organization's operations, the infrastructure of hardware, software, data, and communications required to do so has correspondingly increased in its complexity. Accordingly, the need to better manage the organization's information resources is emerging as a critical issue (Diebold, 1979). The Composite Information Systems (CIS) research program (Madnick and Wang, 1987) represents one attempt to address this problem.

Clearly, one critical dimension of an organization's information resources is its data (McFarlan and McKenney, 1983). Towards this end, the rapidly growing literature of data resource management (DRM) has addressed itself to the more specific problem of how organizations can better manage this component of their information resources. Therefore, it seems warranted to examine how DRM techniques can be applied to the field of CIS.

One DRM technique that has proved to be effective in some circumstances is the adoption of standard data definitions. For our purposes, a standard data definition can be said to exist for an entity when multiple organizational units agree on the definition of that entity (e.g., customer or part number). This applies both to its attributes (fields) and its interpretation in a particular instance. This is an important distinction. It is one thing for the entire organization to agree that a customer data element is composed of an 8-digit number and a name; it is another to agree that Customer A's number is 12345678 and because Customer A is in the database, he is eligible for a $10,000 loan. It is this broad sense that standard data definitions are used in this paper.

It is obvious that organizations could benefit from establishing and maintaining such standards, just as they have benefited from adhering to PC or communications standards. As will be seen later in the paper, some specific benefits gained through data definition standardization (hereafter referred to as DDS) cited by actual organizations include increased system development productivity, higher quality data, and improved coordination between organization units. On the other hand, it is not clear that these standards can be implemented in practice, or even if standards are always desirable. So while DDS is not a panacea, the experience of several organizations suggests that this topic deserves further investigation. It is the goal of this paper to examine these issues surrounding DDS in some detail, and thus calibrate the potential usefulness of this technique for developing CIS.

The paper is organized as follows. Section 2 provides a context for the discussion by presenting three vignettes concerning hypothetical companies with data management problems. These will be referred to throughout the paper to illustrate the potential and pitfalls of DDS. Section 3 presents a framework for thinking about the tradeoffs inherent in standardizing data and clarifying what DDS means in the context of the paper. Section 4 discusses cases of two actual organizations in which DDS was seen to yield significant benefits, and summarizes the characteristics of these efforts that made them successful. Section 5 examines the limitations of DDS, and the paper is concluded in Section 6.

II. Motivation

What are the kinds of data management problems that DDS might be able to help solve? Below are descriptions of different kinds of data management problems faced by three hypothetical companies. It was felt that three different examples were

necessary so that the utility of the DDS approach could be illustrated in different organizational contexts.

1. Confused Manufacturing Company (CMC) operates 12 different widget manufacturing plants using about a million different parts. Although the plants produce different kinds of widgets, they use some of the same parts to produce them. Each plant has its own unique purchasing and inventory systems, operated by independent IS groups. Moreover, each plant has a different system for numbering parts. Top management feels this arrangement is inefficient. The independent plants should be able to coordinate their ordering of parts so that they can get more volume discounts. Also, the plants should be able to share parts if one plant runs out of a part unexpectedly due to a fluctuation in demand. For cultural and financial reasons, it is considered infeasible to centralize the company's information systems at this time.

2. One-Stop Bank (OSB) offers 10 different kinds of financial services to its clients (checking, savings, mutual funds, etc.). It is currently launching a major effort to provide customers with more personalized attention. Each customer will be assigned an account representative who is familiar with the customer's entire range of involvement with OSB. To achieve this, the representative needs to be able to see on a single screen all of the customer's account balances simultaneously. This is currently impossible, as each kind of account is maintained on an independent data base. Furthermore, some kinds of accounts are indexed by social security number, while others are referenced by a bank-assigned identification number. This means that a knowing a customer's name is not sufficient for determining their account numbers if there are multiple instances of that name in any single database.

3. Bean Counting Inc. (BCI) is a company with several relatively autonomous product divisions. The controller needs to have accurate consolidated cost data on a weekly basis for reporting purposes. However, each of the divisions computes costs in a radically different fashion, and she fears that the data she is getting is unacceptably inaccurate.

These three companies face somewhat different kinds of data management problems. CMC suffers from a coordination problem; the plants cannot synchronize purchasing or share parts. OSB has a data access problem; the various account data cannot be assessed and combined in the proper format. BCI suffers from a problem of data consistency; the data of the various divisions cannot be aggregated in a meaningful way. On the other hand, another problem seems to underlie all three situations, namely a potential inefficiency in the use of IS resources due to the independence of systems with very similar functionality.

We will refer to all three of these companies throughout the rest of the paper. One theme which will emerge is that the degree to which DDS can solve the different problems faced by our hypothetical companies will vary.

III. A Data Standardization Framework

When we talk about DDS, it is important to be clear about the magnitude of the effort being advocated. Obviously, it would be impractical for an organization to attempt to standardize every one of its data definitions and build a total system (see Dearden, 1971). On the other hand, if it were viable to do so, the organization could realize some significant benefits. In short, there exist forces which pull organizations both towards and away from data standardization.

Figure 1 depicts this tension. This framework assumes that the organization currently has incompatible data across organizational units and wishes to resolve these incompatibilities. Given this assumption, it depicts a continuum of choices an organization can make (in principle) regarding the degree of data standardization to maintain. Both of the extremes are caricatures; it would be impossible to implement

either of them in its entirety. Nonetheless, it is useful to examine these extremes, so that the differences can be seen clearly.

At one extreme, an organization could build a complete data model and standardize every data definition in that model across the entire company, completely re-engineering the firm's data infrastructure if necessary. This would be the equivalent of driving a BSP (IBM, 1984) or an Enterprise Model (Martin, 1982) to its logical conclusion. Achieving this would result in significant benefits. The company's data would be consistent and more accurate if aggregated (consider the case of BCI). The company's activities could be better coordinated and more efficient. If all of CMC's purchasing and inventory data were shared and commonly understood, top management's problems would be solved. Third, the organization would have a master data architecture which could guide future systems development (Martin, 1982). Finally, members of the organization would have a much better understanding of the firm's operations, a "soft" benefit (Goodhue et. al., 1987).

On the other hand, clearly such a complete standardization of data definitions could never be achieved. Experience suggests that it is very difficult for organizational units to reach a consensus on exactly what the proper data definitions are (Johnson, 1985). Moreover, most large organizations are sufficiently complex that even with complete cooperation and consensus, building a total data model is time consuming and expensive. This means that it is very difficult to quantify the benefits of such an effort for quite some time, if ever. Finally, by the time the model is built, it is very likely that a change has taken place, so that the model is obsolete before it is even implemented.

Infinite ← Degree of Data Standardization → None

Total Data Model	Focused Standards	Total Semantic Mapping
Pros: -Consistency -Coordination -Architecture -Understanding	← Pros: → -Clear payoff -Managable size	Pros: -Autonomy -Efficiency -Problem-driven
Cons: -No consensus -Expensive -Can't measure payoff -Rapidly obsolete	← Cons: →	Cons: -Reconciling difficult -Maintenance -Technology barriers

Figure 1

At the other extreme, the organization could decide to leave the data of each unit completely intact and build "bridges" which perform all the necessary semantic mapping between a local unit's view of the data and the rest of the organization's interpretation of that data. Multibase's capacity to do view derivation (Landers and Rosenberg, 1982) is one way to implement this approach. If this option is chosen, the autonomy of the individual units could be preserved, which is a mandatory condition in many organizations (such as CMC). Furthermore, to the extent that this solution can be implemented without major effort, semantic mapping is a much more efficient solution to the problem than data modelling.

This approach has a number of pitfalls as well. For one thing, it assumes both that the semantic mapping can be both achieved and maintained. When different units have entirely different ways of doing business (the BCI divisions, for example), it may be impossible to resolve all the data elements into one unifying, interpretable schema. Furthermore, significant changes to the semantic mappers may be required over time--changes which could have been avoided if all units were standardized. Finally, there are technological barriers which need to be overcome in the area of semantic mapping. For example, the author is not aware of a system which can perform heterogeneous database updates and guarantee data integrity.

It seems clear that neither of the above extreme choices is viable for most organizations. On the other hand, it seems reasonable to assume that organizations could benefit from *some* degree of either data definition standards and/or semantic mapping. Therefore, having seen the pros and cons of both extreme approaches, we now discuss an approach with is a compromise between these two extremes, referred to as *focused standards*.

Focused standards might be characterized as a "Critical Success Factors" (Rockart, 1979) approach to data standardization. Recognizing that establishing data standards is a difficult and time-consuming process in the best of circumstances, this strategy attempts to establish standard data definitions only for those entities which are both *critical* and *stable*. By critical we mean they are vital to the organization's operations and must be interpreted or shared among multiple organizational units. By stable we mean that the attributes and interpretation of a particular instance of the entity changes relatively infrequently over time.

The semantic mapping element of this strategy comes into play in the way in which organizational units adhere to the standards. It is not required that an organizational unit adhere to the standard in its operations; all that is required is that if another organizational unit asks for standardized data, the former unit agrees to provide accurate, interpretable data in the standard format (see Johnson, 1985). Presumably semantic mapping will have to be done to achieve this.

While the relative merits of this strategy will be discussed in detail later, two points are worth noting briefly here. One, attempting to standardize the definitions of only the most critical data entities increases the chance that the DDS effort will both have some positive impact and be of a manageable size. Two, the approach being advocated is bound to embody a combination of both the advantages and disadvantages of the two extreme approaches.

In summary, the purpose of this section was twofold. One purpose was to describe the tradeoffs inherent in standardizing data definitions. The other was to clarify the kind of DDS approach that is being advocated in this paper, namely *focused* standards. It will be argued that this approach represents a useful middle course for

many organizations. To do so, in the next section we discuss cases in which this approach has worked in two actual organizations.

IV. Examples of DDS in Actual Companies

This section contains synopses of DDS activities found in two companies studied by the Center for Information Systems Research (CISR) (Johnson, 1985; Ney, 1986; Goodhue et.al., 1987). Both these companies were seen as being relatively successful at data management, of which standardizing data definitions was one component. The synopses are presented for purposes of comparison. At the end of the section, the elements which made both efforts successful are summarized.

LDI Electronics -- A Long Data Management Tradition

Two basic features of their information resource system -- basic business codes and a three-tiered systems architecture -- have been the keys to success in data management at LDI, a major electronics manufacturing firm with a decentralized management style.

Twenty years ago, top management initiated the development of a set of codes to identify high-level entities used in systems shared across organizational units. These codes were known as basic business codes. Examples include customer number, employee number, and product number. The total set of basic business codes currently numbers thirty. The only data definitions which are standardized are those few that are critical. These codes have been found to be very useful in maintaining consistency across applications. LDI is quite serious about enforcing these standards, to the point that several companies which they acquired were contractually compelled to convert to LDI's codes.

More recently, as the number and kind of systems in the company burgeoned, it was recognized that different levels of standardization were most efficient for different kinds of systems. Some classes of systems should be standard throughout the company, such as payroll systems. These systems were designated as *global* systems. Other kinds of systems, known as local systems, served local needs only, such as some spreadsheet applications. No standardization was required for these kinds of systems. However, there also existed a third class of systems which could and should be shared to some extent, such as order processing systems. These systems became known as *canned* systems. Together, these three kinds of systems provided a useful way of characterizing LDI's application portfolio.

This three-level systems architecture positioned LDI to implement an effective evolutionary systems integration strategy. All I/S personnel are aware of the architecture, and as a result, are always looking for opportunities to turn local systems into canned systems. When systems are upgraded from local to canned, the integration is made much easier because of the presence of the basic business codes.

LDI represents an example of a company that has a long tradition of managing data, doing so long before organizations recognized data management was an important issue. As a result, they have been highly successful in managing their data through the use of standard data definitions. The next company was not so fortunate and had to resort to other methods.

Foothill Computers -- Building Coalitions

LDI was unusual in that it has reached an end state with respect to the number of data elements with standard definitions. Foothill Computers is in the much more typical position of having many fewer standard data definitions than are needed.

In the late 70's the MIS department at Foothill began to recognize that data management was emerging as a key issue. Perhaps their most serious data management problem was a lack of consistency in data which flowed across functional boundaries. After several largely unsuccessful attempts at "top-down" data modeling, it was decided to take a more "bottom-up" approach by developing and implementing standard data definitions.

In 1984 a cross-functional ad hoc committee, the Key Data Task Force, was established to identify and standardize the definitions of critical data elements. It was felt that performance of this activity was important enough to warrant the concentrated attention of a number of people. Over time, responsibility for this task will be transferred to the Data Administration function.

Through the efforts of this task force, 23 data standards were developed and implemented. Foothill feels that the time invested in the standards has been well spent. What is so interesting about this effort is not the standards themselves, but how they were implemented. There are two features of the implementation which deserve special mention: the controller function and the Standard Data Policy.

For each data definition standard established, a "controller" was designated. This person was responsible for the initial development, and just as important, the support of the definition once it has been approved. In other words, if, after the standard has been approved, someone wants to change the standard, they must obtain the approval of the controller. Note that controllership does not imply ownership, that is, responsibility for integrity of the standardized data. This too was a task of the Data Administration function.

The task force chose the controllers carefully. In each case, he or she was a line person in the business area which was the primary source of the data element

standardized, rather than a dictator from on high. Thus, the standard had credibility in Foothill's decentralized culture. In addition, the overhead associated with supporting the standard was minimized, since only one person's approval would be required to change it.

The Standard Data Policy was developed in response to the problem of getting decentralized organizational units to adhere to centralized standards. Under this policy, the units are not required to automatically convert to the standard; all that is required that they be able to provide standardized data at the "interface level", that is, when another unit asks for it. The unit can choose to convert to the standard or perform semantic mapping to do this. If two units are exchanging nonstandard data, they are free to maintain the status quo.

The idea behind this policy is that setting a standard and slowly building a critical mass of support for it is preferable to forcing compliance. As more and more people support the standard, eventually it will be in the self-interest of all involved to follow it. This kind of policy was seen as the only one which would be viable in such a decentralized organization. Studies of the adoption of other kinds of standards (e.g. Sirbu, and Zwimpfer, 1985) tend to support this assertion.

Conditions For Success

Although LDI and Foothill achieved similar results in different ways, there were conditions common to the success of both efforts. The following list borrows in part from Goodhue et.al., 1987.

- *Minimal line cooperation.* Both LDI and Foothill were decentralized organizations. The divisions could have violently resisted the standards, but chose not to, in large part because of self-interestedness (see below).

Therefore, they cooperated at least to some minimal extent. This is obviously a necessary condition.

- *Initial narrow scope.* Both companies have concentrated their DDS efforts on those few data elements perceived to be critical. These will serve as the foundation for more extensive standards in the future if desired.

- *Clear objective.* At LDI the basic business codes were adopted out of a desire to maintain a single company image to outsiders. At Foothill data standards were developed out of a desire to better coordinate organization units. In neither case were standards developed for conceptual reasons alone.

- *Self-interestedness.* The programmers and analysts at LDI loved the basic business codes because they made system development much easier, and the managers loved the three-tiered architecture because it economized on their development resources. At Foothill, IS management is banking on the critical mass of support for the standards to induce everyone to comply.

So far this paper has extolled the virtues of DDS. That having been done, we now turn to a discussions of its limitations.

V. Limitations

There are a number of factors which are bound to influence the relative successfulness of DDS in a particular organization. Below is provided a summary of these factors.

The first predictor of DDS success is an organization's *capacity for change.* In most organizations resistance is a fact of life. DDS is primarily an *organizational* solution which requires some amount of organizational change for its implementation, perhaps more than some other possible solutions.

One of the most important changes DDS necessitates is a change in the ways organizational units actually transact business. These changes can have significant

implications. For example, if a BCI division has to change its cost computation method to adhere to a data standard, it could affect its profits in the next quarter. Another potential change DDS could cause is the abandonment of systems with large sunk costs, both in the money spent for its development and the expertise of those who use or maintain it. A third potential change is that IS personnel may need to develop a different skill set when working with standards. They will need to develop organizational skills to develop and maintain data standards; it will not be sufficient to possess expertise at using data dictionaries (Johnson, 1985). To the extent that parts of the organization find these changes to be for the worse, DDS may be resisted.

An issue very much related to organizational change is the tendency of data standards to *centralize control* (Goodhue et. al, 1987). When corporate headquarters can interpret data from an organizational unit, it is able to monitor that unit much more closely Most units of decentralized organizations are quite aware of this fact. It should be noted that the semantic mapping solution does not avoid this problem either.

Another characteristic of DDS is that it is an *incremental approach.* It usually takes some time before standards are implemented. Therefore, the benefits derived may be modest originally and then accumulate over time. In other words, if a "big bang" is expected, DDS might not be the right strategy.

A fourth issue which has not been addressed in this paper is the extent to which DDS can be used to develop *interorganizational systems.* Interorganizational DDS is roughly similar to the concept of an application layer protocol. A full discussion of this issue is beyond the scope of this paper, but we can say that it seems safe to assume that there would sometimes exist some minimal level of cooperation among customers and suppliers such that DDS may be viable.

A fifth concern which DDS does not address at all is the problem of *data access.* DDS does not concern itself with where standardized data will be stored. For example, data standardization would not be anywhere near sufficient for solving OSB's problem. Finally, since DDS is a combination of data modeling and semantic mapping, one runs the risk of obtaining *all* of the disadvantages and *none* of the advantages of both techniques. In other words, the worst case scenario is terrible.

Clearly, then, DDS is not the total solution. On the other hand, some other kinds of solutions share many of the same limitations and problems. Despite its limitations DDS compares favorably with some other approaches.

VI. Conclusion

In this paper, it has been argued that DDS represents an approach to data management which can be useful. In particular, it combines some of the useful properties of data modeling and semantic mapping. Furthermore, actual organizations have utilized this approach and found it to be beneficial. The approach suffers from some limitations, most notably the requirement of significant organizational change and lack of attention to data access. All factors considered, it is an organizational solution which is relevant to one dimension of the design of CIS.

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STANDARDS FOR DATA EXCHANGE IN AN INTEGRATED ENVIRONMENT: A METHODOLOGICAL APPROACH

MAHER KALLEL

Significant advances in information technology have created opportunities for strategic applications and for gaining strategic advantage through the integration of different systems within and between organizations. A major thrust for the success of this integration is the development of appropriate standards for data exchange.

This report defines methods for the development of standards for data exchange in an integrated environment. We approach the development of a standard as a problem solving process where the fundamental issues to be addressed are: Problem definition and decomposition, task distribution and coordination and validation.

This technical report is based on a literature survey and a study of the development of the Product Data Exchange Standard (PDES). We identify major technical and organizational challenges in the development of the PDES standard and provide methods that address the different problems. We then generate a set of recommendations for the future development of PDES and for the development of data exchange standards in general.

TECHNICAL REPORT #7

1.INTRODUCTION

The development of a new major product or a service within any organization involves several stages. This development depends on the environment and in particular on the different suppliers, subcontractors and buyers. The systems corresponding to the different stages of processing and the various contractors are usually non-portable and non-compatible. Integration of different systems creates opportunities for strategic applications and can lead to an important competitive advantage. For example, Porter[1985] argues that linking the different stages of a product or a service can spawn new businesses, change the industry structure and create a significant competitive advantage. Furthermore, several case studies[Beeby,1986; Cici,1986] show that integrating information systems and computer applications within a company results in important cost savings, allows a better coordination and planning in the company and enhances the overall productivity of the organization. This integration in turn requires development of standards for data exchange.

The problem of developing a standard of data exchange which links several independent systems and applications is not simply a technical problem. Several types of issues are involved such as:

- How to define an appropriate neutral representation for the data given the diversity of the objectives and requirements of different groups and organizations ?

- How to make the representation of the data independent of the applications and the current technology ?

- How to distribute the tasks for the development of the standard so that a result can be reached in a resaonable amount of time?

- How to reach consensus between the developers of the standard and also gain acceptance of the industry ?

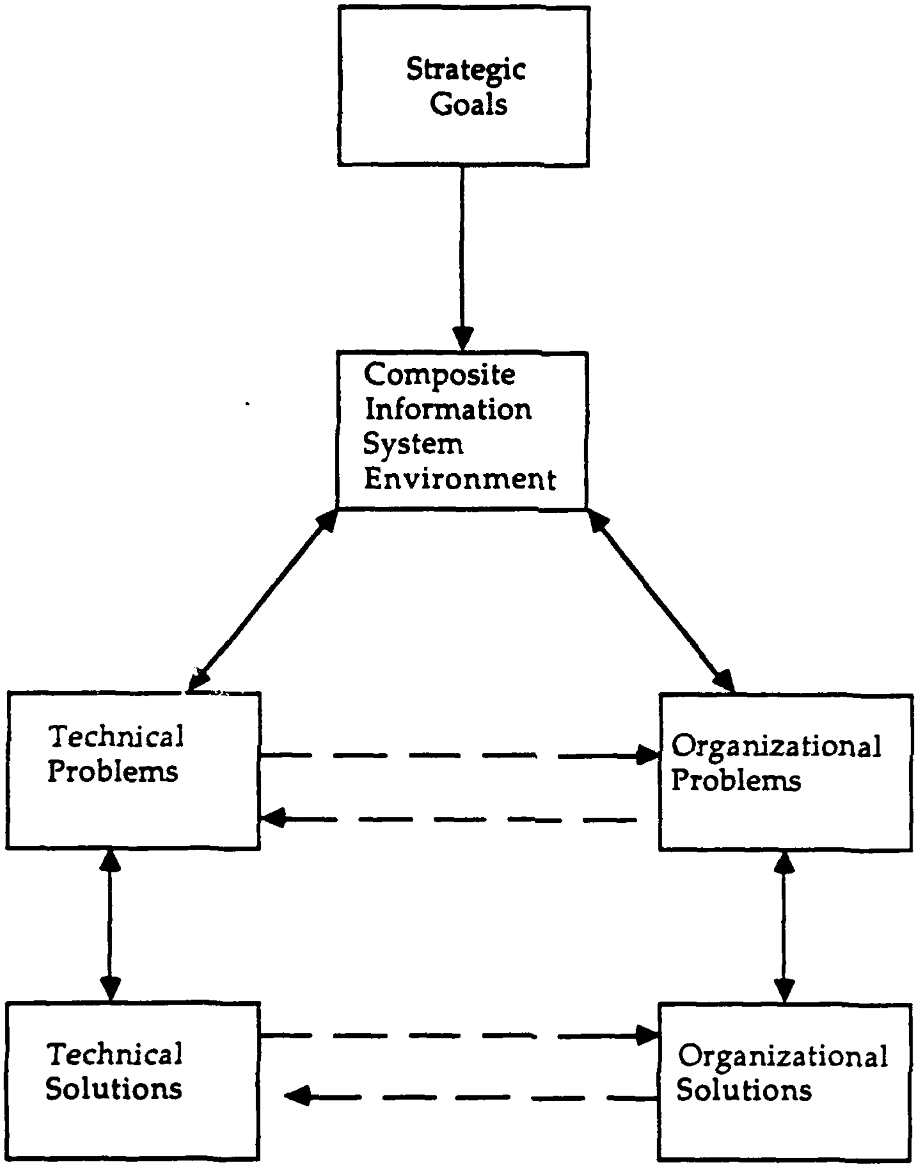
In fact, the development of a standard for data exchange in an integrated environment involves integration of independant systems that cut across traditional organizaional boundaries.

The above kind of system has been considered by Madnick and Wang [Madnick and Wang, 86 and 87] as an example of Composite Information

System (CIS). Madnick and Wang consider the development of a CIS (Figure 1.1) as a four stage process :

- Specification of strategic goals.
- Identification of a CIS that meets the strategic goals.
- Identification of technical and organizational problems associated with the CIS.
- Application of knowledge in organization and information theory to solve the problem.

The organization of this paper is based on this framework. Chapter Two studies the environment for the development of standards. It identifies PDES as a standard that possesses the potential for becoming a future standard for an integrated environment. Chapter Three identifies the major technical and organizational problems involved in the development of PDES. Chapter Four addresses the different problems mentioned by individuals in the PDES development process. Chapter Five summarizes the recommendations for the future development of PDES and for the development of standards for data exchange in an integrated environment.



CIS Process Model (Madnick and Wang)

Fig 1.1

2. REVIEW OF PRESENT STANDARDS AND THEIR ENVIRONMENT

2.1. Categorization of standards

The literature distinguishes between several kind of standards. [Bottaro,1981] divides the standards into four functional categories:

- Informal standards which define terminology or the procedure for defining product properties measurement and testing methods.
- Quality standards which define minimum levels of performance of a product.
- Variety reduction standards which reduce the number of versions of a product. The main motive behind variety reduction standard is the potential economies of scale.
- Compatibility standards which provide a mean for complementary product to work together.

The distinction between different standards is not always clear and a single standard may serve several purposes. However, standards for data exchange are primarily compatibility standards.

Compatibility standards have been furthermore classified in two different categories:

- peer to peer standards that allow a functional communication between two identical products such as two modems.
- interface standards which allow the interworking of two or several different products.

Our focus will be essentially on interface standards.

Soch (1980) distinguishes three different ways of standardization:

- De-facto standards which are recognized by the industry without any formal adoption process. They are the result of strong marketplace adoption. A typical example of a de-facto standard is the IBM personal computer.
- Presentation of an innovative product design to a standard organization for ratification as a formal standard. The firm presenting such a standard aims to increase its market share and obtain a competitive edge at the cost of sacrificing its technical edge.

- Formal standard in advance of any commercialization of the product or service.

In this thesis, we consider compatibility standards that are based on a formal process of standardization.

2.2. Economic rationale for the development of interface standards

Consider N users who wish to communicate between each other and have N different systems.

In the absence of compatibility standards,a bilateral negotiation is carried out between each user. Thus the number of agreements that must be negotiated is at the limit $\frac{N(N-1)}{2}$. If N is big, the number of negotiations becomes prohibitive.

On the other hand, if only one standard is adopted, separate bilateral negotiations are replaced by one multilateral negotiation. Bilateral negotiations are eliminated while the cost of a more difficult multilateral negotiation is incurred.

let C_1 : the cost of negotiating one bilateral agreement

C_2 : the cost of ensuring compliance with one bilateral agreement

Q_1 : cost of compliance with the standard

Q_2 : cost of negotiating the multilateral standard

S : savings

The total savings for a user is

$$S = N(N-1)(C_1+C_2) - NQ_1 - Q_2(N)$$

The cost of compliance with the standard in the case of a product data exchange standard will be the cost of building of translators between the format generated by the application and the neutral format in the case of the standard unless the translators are already implemented.

2.3. Administration and standard development by formal organizations

In the USA several organizations are formally recognized as standardization bodies. Contrary to the European countries where standards are written in law, the standards that are generated by these

organization can not be imposed nor enforced and consequently standards are in general voluntary and a standard will be adopted not on the merit of its text but on the evidence that the standard meets a valid need and that an important majority of the companies and organizations that will be affected by the standard will accept it. Thus, a standard setting body concern is for wide consensus and maximum compliance by the industry.

The most important standard setting organizations in the field of data exchange and in general information technology are:American National Standards Institute (ANSI), International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), International Telegraph and Telephone Consultative Committee (CCITT), Institute of Electrical and Electronics Engineers (IEEE), Accredited Standards Committee (ASC) on Information Processing Systems (X3), and National Bureau of Standards (NBS).

2.3.1. ANSI

ANSI is the coordinating organization for America's federated standards system. Its membership includes 900 companies and 200 trade, technical, professional, labor, and consumer organizations.

ANSI does not itself develop standards, but accredits technical organizations as standards developers. ANSI approves the standards developed by the accredited organizations as American National Standards and makes these standards available for purchase by industry, government, and the public.

In order to obtain approval from ANSI, several methods can be used:

- the accredited organization method : under this method, specific organizations are approved for standard development. A typical example of such organizations is the Institute of Electrical and Electronic engineers which develop standards in areas such as software engineering and communications.

- the accredited standards committee method : Under this method, special committees such as the X3 Accredited Standards Committee (ASC) on information processing systems are established to develop and review standards. These standards will then be submitted to the management board of the ANSI for approval.

- <u>The canvass method</u> : a sponsoring organization subjects a standard that has been already developed by some organization to an extensive canvass of affected interested parties.

ANSI is the USA member body of ISO and as sponsor of the US National Committee is the US member of the IEC. ANSI helps govern ISO through membership on its council, executive committee and technical board, and coordinates the USA participation in the work of ISO technical committees, subcommittees, and working groups.

2.3.2. The X3 Accredited Standard Committee

The ASC/X3 committee is administrated by the Computer Business Equipment Manufacturers Association (CBEMA) and is accredited by ANSI for developing standards in the information processing area. It has about 30 technical committees that are supervised by the Standards Planning and Requirements Committee (SPARC). All new project proposals must be approved by SPARC before they can be acted upon by X3.

Example of technical committees are: The ASC/TC X3H3 is the computer graphics technical committee which was formed in 1979 and has developed standards such as Core, General Kernel Standard GKS, Computer Graphic metafile (CGM), and Programer's Hierarchical Graphics Standard and X3V1 Office and publishing systems which is developing Standard Generalized Markup Language (SGML).

2.3.3. The ASC/Y14 Committee

This committee is accredited for the development of standards for engineering and related documentation practices and is administered by the American Society of Mechanical Engineers.

The subcommittee 26 of the Y14 committee which is the computer aided preparation of product definition data is the origin of the development of The Initial Graphics Exchange Specification (IGES) and the Product Data Definition Exchange Standard (PDES).

2.3.4. The IEEE

The IEEE is an accredited organization of ANSI that acts internationally through the U.S. National Committee for the IEC and through ANSI (the U.S. member-body) for ISO.

The IEEE is the largest technical society in the world. It recommends standards in many areas of electrotechnology such as standards for local area network (committee 802) and portable operating system environment (committee 1003).

2.3.5. The International Standard Organization

The ISO develops, coordinates and promulgates international standards that facilitate the international exchange of goods and services and encourage cooperation in the sphere of intellectual, scientific, technological and economic activity. They cover all fields, except electrotechnical, which is the responsibility of IEC. ISO work is carried out by 163 technical committees and approximately 2100 subcommittees and working groups.

The standardization work in ISO is carried out through technical committees (TC) which establish Subcommittees (SC). Each SC is composed of several working groups (WG).

Each ASC has the responsibility for the development and coordination of US positions on standards development within the ISO. The US Technical Advisory Groups (TAG) are groups designated to carry out this responsibility. Each ASC, in turn, has organized TAG to cover specific subject areas or has assigned TAG responsibilities to existing technical committees.

For example, ASC/Y14 has the TAG responsibility for issues within TC184, Industrial Automation Systems. This committee has five subcommittees. The committee SC4 is in charge of the external representation of product model data. This committee is responsible for the development of the Standard for Exchange of Product model data (STEP). PDES represent the USA position and is the basis for STEP development. SC5 is in charge of reference models.

The international counterpart of ASC/X3 is TC97. For example, the SC18 is developing standards for Text and Office System (SC18), which covers office

document architecture, office document interchange format, and integrated text and graphics content architectures; and Information Retrieval, Transfer and Management for "Open Systems Interconnection". (SC21) develops standards for database, computer graphics and data dictionaries.

2.3.6. The National Bureau of Standards (NBS)

The standard development and associated activities of the NBS aim to help federal agencies improve the acquisition and information processing systems. The main areas of this activities are hardware, software and data interchange standards.

NBS contributes to the development of industry-wide computer standards by leading and participating in the work of more than 70 industry standards writing committees operating under the auspices of ANSI, ISO, and IEC. For example, the NBS leads the development of IGES and PDES. the chairman of the IGES organization is also the chairman of the ISO/TC184/SC4 committee.

Voluntary standards that NBS identifies as potentially beneficial for the Federal government are proposed as Federal Information Processing Standards (FIPS). The FIPS Publication Series is the official publication channel for standards and guidelines adopted and promulgated under the provisions of Public Law 89-306 (Brooks Act) and Part 6 of Title 15, Code of Federal Regulations. These legislative and executive mandates have given the Secretary of Commerce important responsibilities for improving the utilization and management of computers and automatic data processing in the Federal government.

NBS develops the implementation and validation of the standards through Institutes such as the Institute for Computer Sciences and Technology (ICST). NBS develops test methods and measurement techniques that enable users and vendors to test products for compatibility and conformance to standards.

States and local governments and industry submit comments on the benefits and impacts of the standard. All comments received on proposed standards are reviewed and analyzed by NBS. Based on its analysis and all available information, NBS recommends the standard for approval by the Secretary of Commerce for government use. Approved FIPS are announced in the Federal Register, published in the FIPS Publications series and made available to the public through the National Technical Information Service.

2.3.7. The ANSI formal standardization process

We describe in the following the formal standard development process within the X3 committee. IEEE or Y14 development process are functionally similar.

To start a new standards project, a technical committee must draft and recommend a project proposal (known as an SD-3 or Standing Document 3). The SD-3 must then be approved by SPARC and is then subject to a ballot vote by X3. Any negative comments submitted with the ballot must be resolved before technical work can proceed. This stage takes at least six months.

The X3 technical committee then prepares a series of working drafts that are circulated and commented . This stage requires a minimum of one year but takes in general several years.

When the technical committee believes that the proposed standard is sufficiently stable, it votes to forward the draft for public review and to solicit opinions from outside the committee. If approved by TC97, SPARC reviews the document for conformance to the SD-3. X3 then conducts a 30-day ballot (with a possible 15- day reconsideration period) on forwarding the draft to ANSI for announcement of the public review period.

The standard is then submitted for public review. The initial public review period is four months; subsequent public review periods are two months. After each public review, the technical committee prepares responses to the written comments that were submitted, and then votes on whether to approve the proposal. All negative comments must be resolved at each ballot stage. If substantial technical changes are made to the document as a result of this process, a new public review cycle begins. This cycle may invite comment on the entire document again, or it may be restricted to those changes made to the previous draft. This stage takes at least eight months. Most X3 standards, because of their size and complexity, require at least two public reviews before final approval.

When the technical committee has approved a document after a public review that results in no more substantive technical changes, there is a six-week ballot on forwarding it to the appropriate ANSI Board of Standards Review (BSR) for acceptance by ANSI. The criteria for acceptance by the BSR is not technical merit but the consensus on the standard. If BSR approves the document, it authorizes ANSI to publish the X3 document as an American National Standard. This final stage can take six to nine months, depending upon how long it takes the document editor to put the document in a format that is acceptable to ANSI. The document is then sent to publication for final printing.

2.3.8. The ISO standardization process

In the ISO standardization process, a new project begins when a subcommittee or a standard setting body proposes a New Work Item (NWI) and submits it to a technical committee for a three-month letter ballot. Usually, a technical committee or the appropriate TAG recommends the USA position. The base document defining the US position is forwarded to the technical committee via ANSI. This stage takes five to eight months.

From the base document, the working group prepares working drafts that are circulated for comment by the subcommittee member bodies. This comment period is usually three months. The relevant technical committee or TAG prepares the US comments and forwards them to ANSI for submission to the ISO subcommittee. The drafts are developed at Working Group meetings. Working Group meetings are held once or twice a year. The Working Groups may create special working groups, called Rapporteur Groups, to undertake specific tasks between meetings. This stage takes 12 to 18 months.

When the working draft is complete and major issues have been solved, the working group recommends that the subcommittee register the document as a Draft Proposal (DP). The relevant USA TAG or accredited standards committee develops a recommendation for the USA ballot and forwards it to the subcommittee. If the recommendation is accepted, the Central Secretariat of ISO assigns an ISO number to the proposed standard.

the Draft proposal is then sent for a three- month ballot among the subcommittee member bodies. Again, the relevant USA TAG or accredited standards committee prepares the ballot recommendations and forwards it to the ISO subcommittee. Changes are made to the document, as necessary, to achieve consensus. Additional DP cycles, each requiring a three-month ballot within the subcommittee are usually needed. This stage takes a minimum of 12 to 14 months.

When consensus has been reached on a DP, the document is considered technically stable. After the DP has been put into an appropriate ISO format, it is sent by the ISO Central Secretariat for a six month ballot. The document is now called a Draft International Standard (DIS) and its designation is consequently changed .

The document is then subject to several comments from the committee, the editing sub-committee or the working group. If the document is substantially changed anther Draft International standard is required. In general, multiple DIS rounds are avoided and a standard will not reach the DIS stage if the technical issues are not yet solved. The final International Standard (IS) text is then submitted to ISO Central Secretariat. Upon approval by the ISO Council, it is then published by ISO.

2.3.9. Implications of the standardization process

The standardization process is based on voluntary participation and consensus and any minority can influence the process.

The ANSI standardization process takes at least 3 years and a half. However in reality it takes in general from 5 to 8 years to publish the standard.

The ISO process is slower and will take at least 6 to 7 years. Consequently, if the standard is built around the technology at the moment where the standard process starts, it will approach technological obsolescence by the time it is ready for use. GKS is a good example of this. GKS is an adequate model for the technology of the late seventies and early eighties but is an inadequate platforn for 3D applications, hierarchical modeling, local rendering of solids

and local raster operations on bit-map workstations. A 3D version of GKS is now being developed but the standards still trying to catch up the technology.

2.4. Presentation of graphic standards

Standards for graphic data exchange between two systems has to be seen as part of a general graphic environment. In this environment, the standards can be divided in three functional categories:

Graphics application interface standards: standards such as The core system, GKS and PHIGS relate to the graphics application interface. At this level the concepts and ideas of the human operator are translated into a graphical form that can be processed by a computer system.

Exchange of graphic data standards: CGM and to a certain extent IGES are standard used for communication of graphic data between two systems. They code the data independently of how the data was created or how it will be displayed (device and application independence). As we will see later in this chapter, Graphics are only a part of a more general product definition data in IGES. However, several concepts on which the standard is built are relevant to the graphic field. CGM has a very efficient encoding of pictures allowing a fast transmission of these data.

Graphic device software interface standards: the North American Presentation Leve Protocol Syntax) NAPLAPS is a standard that defines the data transmission interface for hardware with data processing and data storage capabilities. The Computer Graphics Interface (CGI)on the other hand creates a universal interface between the upper levels of graphic software system and its device drivers independent of the display, recording or interactive-input hardware.

As presented here, the standards address different graphic functions however, these functions are not independent. For example, if there is no provision for a standard for exchange of data to handle non standard graphic primitives that are generated at the application level then it will not be possible to transmit the data.

	Graphic Dimensionality	NUMBER OF PRIMITIVES	HIERARCHICAL LEVELS
CORE	2 and 3D	25	primitives temporary segment retained segment
GKS	2 and 3D*	12	primitives segment primitive outside segments
PHIGS	2 and 3D	14	primitives retained structure root structure subordinate structure temporary structure archival structure
IGES	2 and 3D	88	entities associativites macros subfigures views drawings
CGM	2D	9	primitives
CGI	2D	22	primitives segments
NAPLAPS	2D	24	primitives macros

*GKS - 3D Extensions

<u>COMPARISON BETWEEN DIFFERENT CHARACTERISTICS OF GRAPHIC STANDARDS</u>

TABLE 1

The CGI primitive repertoire of primitives offers a rich variety of graphic forms that the application interface standards such as GKS do not have. In order to make the system more user friendly and reduce overhead, one may attempt to build a non-standard application interface based on the CGI repertoire. Consequently, the application will be incompatible with the standards.

Table 1 compares the different graphic standards.

2.5. General description of IGES

2.5.1. Development of IGES

In June 1970, the ANSI Y14.26 subcommittee was formed under the chairmanship of McDonnel Douglas to address the Computer Aided Preparation of Product Definition Data. In 1973, the task group Y14.26.1 of this committee was formed with the objective of generating a standard for the "digital representation of object shapes". The scope of this task group extended to the representation of 3D geometric objects. Several other task groups were formed later. One of those is the Y14.26.11 which addresses the standardization of the digitized non-geometric product data definition.

The first draft of the Y14.26.1 was published in 1976 and in August 1979, it was decided that it would be released as a draft standard for a one year public period review following a manual testing of the specification.

In the same period, the Department of Defense funded through the Air Force Integrated Computer Aided Manufacturing (ICAM) program the creation of an Initial Graphic Exchange specification. The objective of this effort is the formulation of a standard for use in communicating drawing and geometric data between commercially available CAD/CAM systems in a very short time.

For this purpose, Boeing released its CIIN (CAD/CAM Integrated Information Network) specification and General Electric released its neutral Database to the public domain to be used as bases for IGES. Within 3 months, a 3 person task group from the NBS, Boeing and GE put together the first draft of IGES and a committee framework was set up to provide technical advice

on the development and the use of IGES and to provide guidance, coordination and publicity within the CAD/CAM community.

Through a joint effort of the IGES and the ANSI Y14.26 committees,the work on the geometric structure of the ANSI Y14.26.1 task group was embedded in the IGES file structure. The result of this effort was proposed to the NBS in May 1980 and was accepted in September 1981. Following the release, there was several demonstrations of transfer of drawings based on subsets of the IGES entities and by August 1983, thirty-one vendors announced plans to provide IGES implementations.

The established committee framework (the IGES organization) led the development and refinement of IGES, provided means of testing the implementation of the standard and gradually expanded its coverage of CAD/CAM application Areas. In February 1983, version 2.0 of IGES was released followed by version 3.0 in April 1985.

2.5.2. Description of IGES

The structure of an IGES file is based on entities. There are in general three type of entities:

- Geometric entities such as points, conic arcs, splines, ruled surfaces and surfaces of revolution.
- Annotation entities are entities that describe non geometric details which appear on an engineering drawing. Example of annotation entities are: angular and linear dimensions, arrow and labels.
- Structure entities: these entities define associations between other relations in the file. General relations can be set up using the associativity entity and a set of viewing parameters and associated annotation entities form a *drawing*. Macros are also provided for parametrized parts descriptions.

An IGES file contains five sections : a *start section* containing human directed information, a *global section* which contains conventions used in writing the file such as number of bits of reprsentation of integers and information about the nature of the model it contains, A *directory entry*

section containing the entities defined in the file, a *parameter data* section containing the data for each entity and a *terminate* section.

2.5.2.1. Problems with IGES

2.5.2.2. Definition problems

The initial IGES specification was drawn up in a very short time. It was not based on a rigorous scheme of semantics. There are redundancies in the IGES entity set leading to a non-uniqueness of the definition of entities. For example, dimension data resides both in the geometry and the annotation entities and there is no explicit relationship between them.

There are also important difficulties in defining free-form curves and surfaces and several systems use entities that have no correspondence in IGES. Moreover, despite the existence of macro entities, IGES has difficulties in the transmission of data related to parametrized family of parts.

Furthermore, the IGES terminology did not correspond,at least during the early phases, to the terminology used by the vendors in the translator. Moreover, there was no specification of a standard method of handling errors.

These problems led to mismatches in the representation of an IGES file by preprocessors and post-processors and a loss and distortion of information during the translation. The different ways of handling these difficulties is an important factor in the "flavoring" of IGES

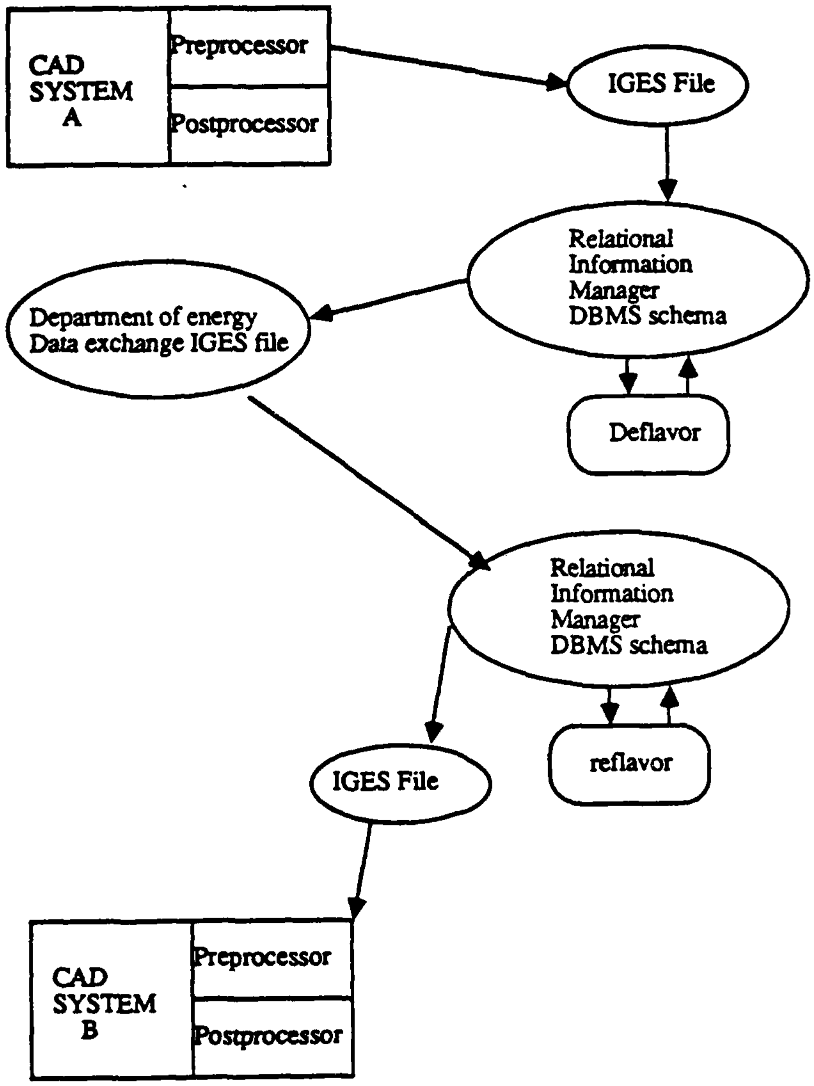
2.5.2.3. Implementation problems

The lack of an implementation guide in the early phases of IGES and a structure for implementation of the IGES specification resulted in a piecemeal implementation of the IGES entities. Each translator writer implemented a subset of the IGES entities.

The non standard implementation of IGES translators and the different problems of definition led to the "flavoring" problem. The implemented translators have different representation of the IGES specification and the

neutral format generated by a pre-processor is not neutral but flavored by the vendor.

In order to transmit a file between two systems and use the neutral file format for archiving of data, a complicated operation of deflavoring, reflavoring have to occur. Figure 2.1 shows an actual example of an exchange of IGES files between CAD systems in the Y-12 Plant[Harper,1987]. A manager



<u>**CAD Data exchange using IGES At the Y-12 PLANT**</u>

Fig.. 2.1

of the plant declared during a discussion I had with him in February 1987 that it took two years to install the flavoring and deflavoring system.

2.5.2.4. Format problems

The IGES specification has a fixed eight columns file format in the directory entry section. Furthermore, an 80 character block must be at least allocated for any entity and entities are specified by entries in two sections of the file. As a result, the size of an IGES file may be several times the size of the original file and despite the important reduction in file size in IGES 3.0 version, the inefficiency in the file format is still a problem. The file format results also in an important translation time.

2.6. General description of PDDI

PDDI is a project of the United State Air Force Integrated Computer Aided Manufacturing (ICAM) that begun in 1982 and is conducted by McDonnel Aircraft Company. This project ends by the end of this year.

PDDI output has been :

- The development of procedures and software for testing the feasibility and implementability of IGES and determining the current level of implementation of IGES. These procedures will be released to the public domain to be used by CAD/CAM users and vendors for validating IGES translators.

_ An effort and emphasis on a more complete quantitative definition of the shape of the part that is the emphasis on solid modeling in which the set of spatial points of an object is completely determined and a qualitative description based on the decomposition of the object into topological entities such as faces, edges and vertices describing the connectivity of a part and form "features" allowing high level communication about parts. Example of features are hole, flange,pocket, chamfer etc... The PDDI feature entities relate specific topology and geometry entities so that identifying information for that feature can be explicit in the data.

- Transmission of shape and non shape information such as administrative data. In fact, the PDDI project was the first attempt to standardize the

transmission of a "complete" product definition that is interpretable by a computer.

2.7. General description of PDES/STEP

The PDES project began in mid 1984 with two primary objectives:

- Develop an exchange standard for product data in support of industrial automation.
- Represent the US position in the ISO and take the leadership in the development of a single worldwide standard for exchange of product data.

" PDES extends the heritage from the standards effort and the research and development efforts for providing means for an organization to communicate its product breakdown structure." [kelly,1985]. Figure 2.2 describes the main influences on the PDES and STEP of other standards and different national and international projects.

2.7.1. Defining PDES

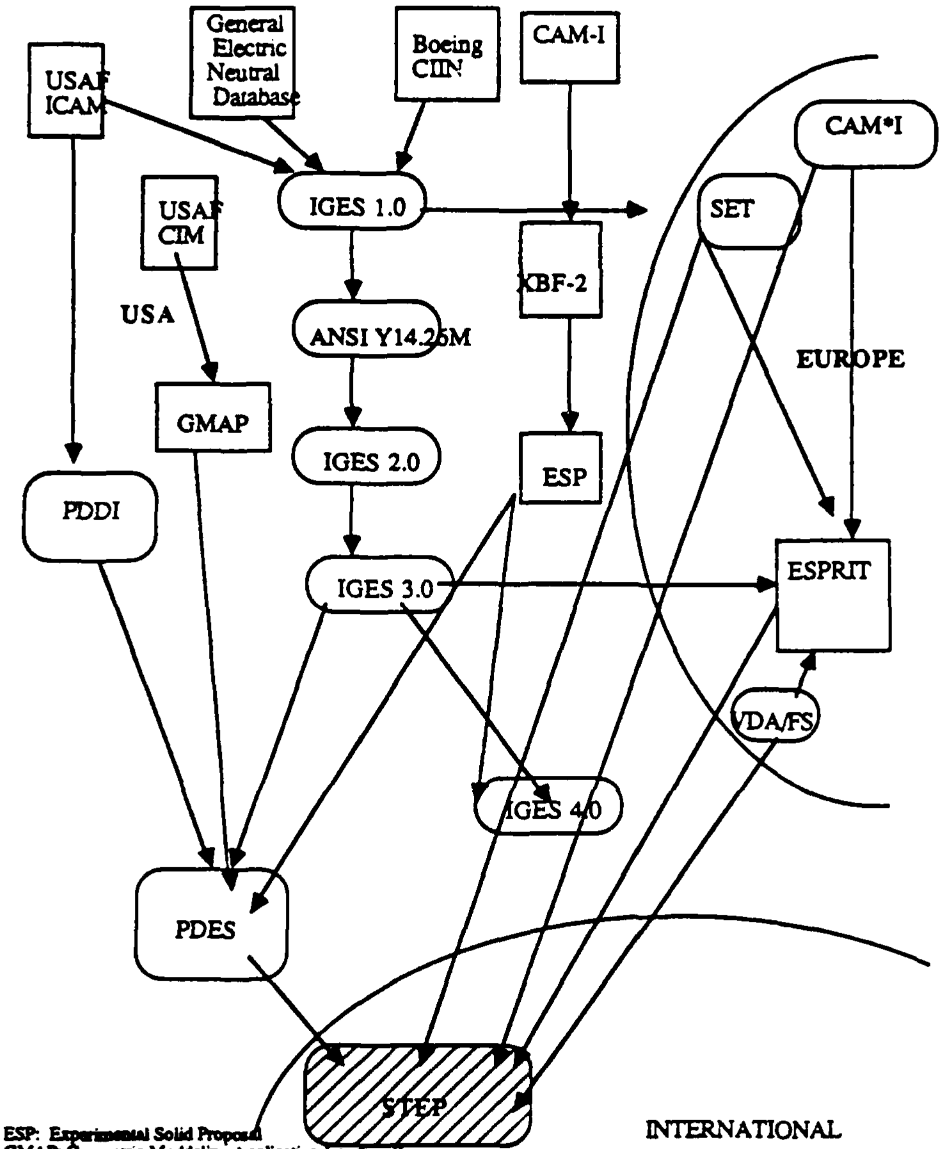
In some documents the PD in PDES stands for Product definition data in others, it stands for product data.

The chairman of the electrical committee distinguishes between four classes of data :

- product data : requirement stated in terms of functional and physical characteristics which should be present in the data when they have been manufactured. It includes text, geometry, and alpha numeric data.
- production data : data describing how the objects are to be manufactured.
- Operational data: data that describes events of production such as lot size, schedule and sequence of assembly.
- resource data: data describing the resources that are involved in operations such as machines,people and money.

He defines product definition data as data including all product data, most production data, some operational data and little or no resource data.

The chairman of the PDES logical layer initiation task stated that "product data " is taken to be more general than "product definition data". It includes



ESP: Experimental Solid Proposal
GMAP: Geometric Moddeling Application Interface Program
CAM-I :ComputerAided manufacturing Inc
XBF-2 : Experimental Boundary File 2
CIIN : Computer
ESPRIT: EuropeanStrategic Program for Research and development in Information Technology
SET: Standard d'échange et de transfert (French)
CAM*I Computer Aided Manufacturing (german)
VDA/FS: German Standard for fre form surfaces

<u>Main influences in the development of PDES/STEP</u>

data relevant to the entire life cycle of a product and that the development of PDES involves settling on a set of logical structures to contain product data information and also settling on the manner in which these structures will be implemented in computer form.

The chairman of the IGES organization defines the Product Data in PDES as the totality of data elements *which completely define a product for* all applications over its expected life cycle. It includes the geometry, topology, tolerances, relationships, attributes and features necessary to completely define a component part or an assembly of parts for the purpose of design, analysis, manufacture, test, inspection and production support. Very little if any process data is included with the exception being aspects like a heat treat specification.

2.7.2. PDES Emphasis

PDES objective and emphasis is an evolving concept. In the following we give the objective and scope of PDES as defined during the first efforts.

PDES objective as defined in the first ISO/TC184/SC4 meeting (1984) is "the capture of information comprising a computerized product model in a neutral format throughout the life cycle of a product".

The essential emphasis is the communication of data and the semantics associated with the data so that there is a sufficient information content as to be interpretable directly by a CAD/CAM application program. For example, tolerance information would be carried in a form directly interpretable by a computer rather than a computerized text form intended primarily for interpretation by a human as it is the case in IGES. This information would be associated with those entities in the model affected by the tolerance.

PDES constitutes in fact a fundamental shift from the other standards that we have described so far. In order to understand this difference we present in the following a comparison between IGES and PDES as defined during the April 1987 meeting on PDES.

2.7.3. Comparison between PDES and IGES

Objective

PDES objective is a complete sharing of product data such as 3D solid geometric representation, manufacturing features, material properties and tolerance specifications between different applications such as engineering analysis, bill of material, CAD directed inspection and automated NC programming at the inter and intra-organizational level.

PDES has thus to be able to receive input from multiple systems, interpret that input and provide selected portions of that back to support different applications so it has to provide an integrated product knowledge shared between different systems. It has thus ultimately to provide access to "product definition knowledge-base" in the sense that it has to interface applications and a global knowledge source that will capture all the relationships and semantics of the data.

On the other hand,IGES objective is only to provide exchange of data between individual systems.

Scope

PDES is intended to support the complete product description throughout the whole life cycle. More specifically, during the recent PDES meeting, it has been stated that PDES should "transfer knowledge between design, manufacturing and support applications (reliability and maintenance) and allow each of these areas to receive feedback from the others.

IGES on the other hand was initially intended for CAD systems.. While this scope has been gradually expanded to include other applications. Its use will be limited to the design stage of the life cycle.

Origin

IGES is based on the CAD/CAM Integrated Information Network of BOEING and the Neutral Database of General Electric. On the other hand,while some of the PDES effort has been based on projects such as PDDI and European project such as ESPRIT and CAD*I, PDES falls into the category of formal standard in advance of any commercialization of the product or service as defined by Soch.

Approach

The approach to the development of PDES standard constitutes a major change that has taken the IGES organization. IGES approach was to directly translate the needs of the users into the physical standard. PDES on the other hand bases its approach to the ANSI/X3/SPARC three layer architecture. It aims to model the whole life cycle using a formal data modeling methodology and integrate the different models of different applications into a single conceptual schema independent of a particular application view of the data and the technology use to implement it resulting in a common knowledge among different applications that is totally consistent between all different views.

Implementation

IGES physical implementation consists in a pre-processor translating the application file format into a neutral file format and then a post-processor that translates it to the receiver format.

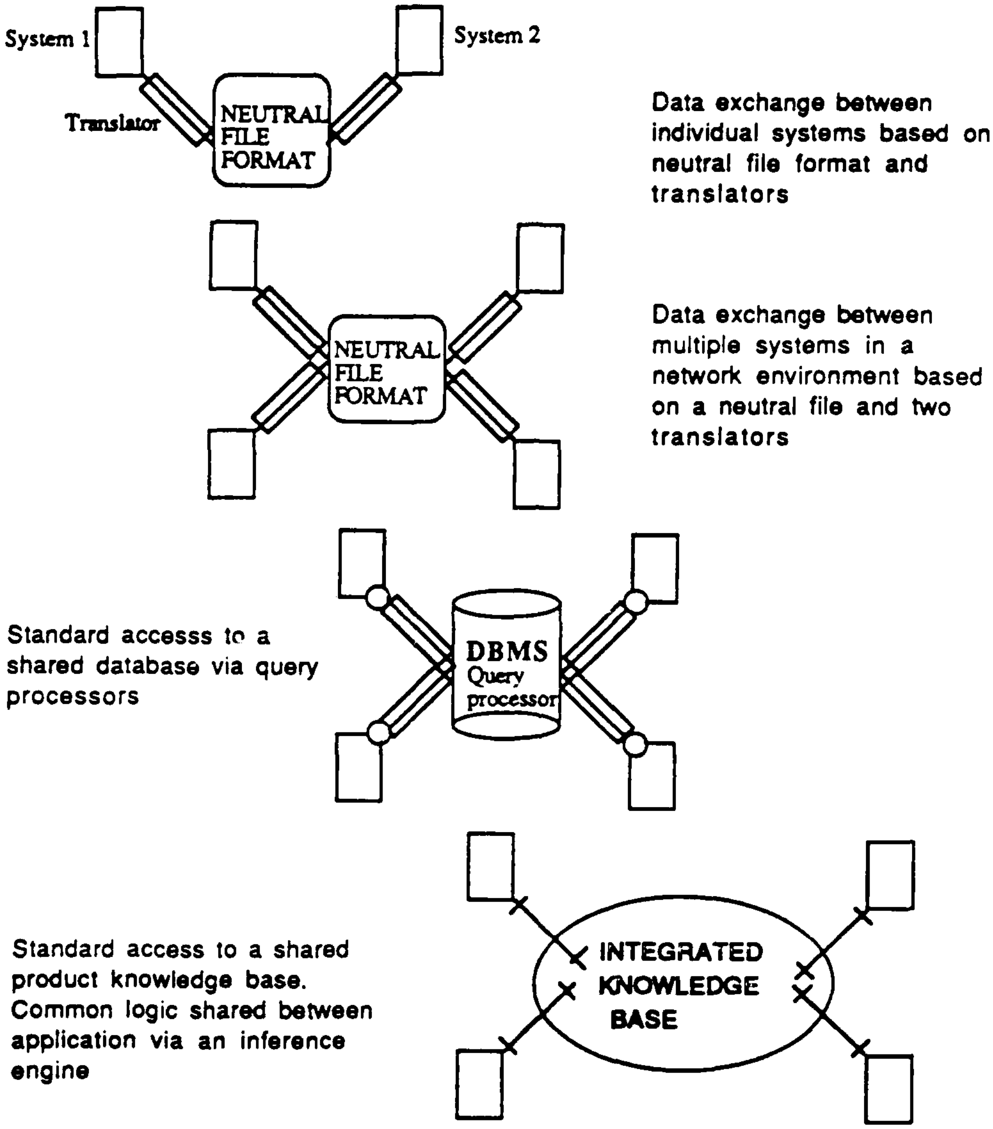
PDES physical implementation is expected to evolve from the previously describe implementation to:

- network architecture for simultaneous exchange of the data between multiple system. Such an implementation would be similar to the PDDI implementation which consists in a
    - working form corresponding to a network model of the data and a logical structuring on how to access the data.
    - access software which is a higher level language
- DBMS where the product definition data is stored into a "classical " database interfaced by a query processor.The exchange of the data would be involve the use of standard language for networking and archiving. As a consequence,there was a debate during the recent PDES meeting on wether PDES scope in this case would be not only the exchange of the data but also its archiving.

_ a knowledge base containing a complete "knowledge" about the whole life cycle of the product interfacing multiple systems. PDES would have to provide a standard interface of the different applications to this knowledge base.

Figure 2.3 shows the different possible implementation of PDES.

Emphasis



<u>FUTURE EVOLUTION OF PDES IMPLEMENTATION</u>

Fig. 2.3

IGES is a national standard that was an answer to a need from the aeorospace manufacturers for exchanging graphic data between dissimilar systems. PDES intends to be not only an international standard

PDES scope is an integrated environment that does not exist yet and aims to generate an integrated conceptual schema for a total product definition. As aconsequence, it is more an innovation and R&D development project than a project for standard at least at the present stage. A participant in the last meeting expressed this emphasis by stating that:

" we want to ultimately have a standard that is going to support us in the 1990's. PDES actually involves creativity and development of capabilities that does not exist. Therefore, it is really a technology development type focus"

Data integrity control

The control of the integrity, completeness and consistency of the data in the IGES case is primarily enforced by the translators so that the translator writer has to make sure that the data transferred is coherent and complete. In a PDES Environment, ultimately the integrity control will be embedded in the data itself. Indeed, in the knowledge base environment, it is expected that the integrity rules will be directly implemented in the data structure.

During the April meeting, a participant remarked that in this case, PDES will not simply standardize the transfer of data but also the data structure.

Table 2 summarizes the comparison between IGES and PDES.

2.8. Summary

In this chapter, we have first distinguished between several categories of standard and defined the data exchange standards as compatibility standard.

We have then shown the rationale behind data exchange standard.

In order to adequately describe and analyze standards, we have described the environment of standardization through the different organization and the formal process of developing a standard within an organization. This description showed that the standardization process is a based on voluntary participation and that the decision making process is a consensus process.

Consequently,it is a slow process and as a result of the technological pace in the field of communication and computers,standard based on present systems had difficulties in answering the needs of the users by the time the standard is ready.

We have then given a general description of several standards.We have first described several functional categories of graphic standard to stress the fact that in an integrated environment standard for data exchange will ultimately have to be upward compatible with other functional categories of standards such as application interface standards.

We have then described some major US standards for data exchange in manufacturing in a chronological order.

This description showed the evolution from standards for an "island of automation environment " to an integrated environment.

We have essentially concentrated on the PDES standard and compared it with previous standards. This comparison reveals the following characteristics:

- PDES is an evolving concept that is perceived differently by the different participants in the process. The different definitions of PDES are of the difference in perception and understanding of what PDES is.
- PDES is oriented a future and totally integrated information system environment which does not exist yet. This constitutes thus an important shift from standards that are based on present systems and present technology and that are trying to catch up with the development in information technology.
- PDES at the present stage is more a technology develeopment project that a standard setting project. This characteristic will be fundamental for the analysis in the following chapters.

The following chapters will focus on the PDES standard because we consider that it constitutes a good example of the standards that will exist in the future and that aims toward an integrated environment

3. THE PDES PROJECT

In describing the PDES development process , we distinguish three strongly related issues requiring specific concepts and specific approaches: project management, modelling and validation.

Project management relates to the different policies that govern the design process. It reflects :

- The physical constraints that are imposed on the project such as time, money, personnel and required facilities.

- The constraints resulting from the interaction of the users, the designers and the decision makers.

Project management will thus usually consists in the organization, planning and supervision of the development process. Typical tasks in project management are the timing of different phases of the process, different activities in each phase, description of the product of each phase and the coordination among different phases.

Modelling relates to the architecture, tools, work guidelines and techniques that govern the design. It expresses a way of thinking about how to acquire knowledge as well as how to derive specifications from this knowledge.

We purposely differentiate between these three tasks since we consider that each aspect requires a different approach and concept.

3.1. Project management

3.1.1. Plan of the PDES project

The plan of the Project as stated in the PDES initiation activities report [IGES,1986] is:

- Development of a proof of concept for PDES. These initiation activities would serve as a baseline for future activities.

- Development of PDES version 1.0. This version will provide a standard for product data exchange involving mechanical piece part, mechanical

assemblies,electrical printed wiring board product, Architecture Engineering and Construction (AEC) models, Finite Element Modeling and drafting applications. An explicit path relating IGES to PDES should exist.

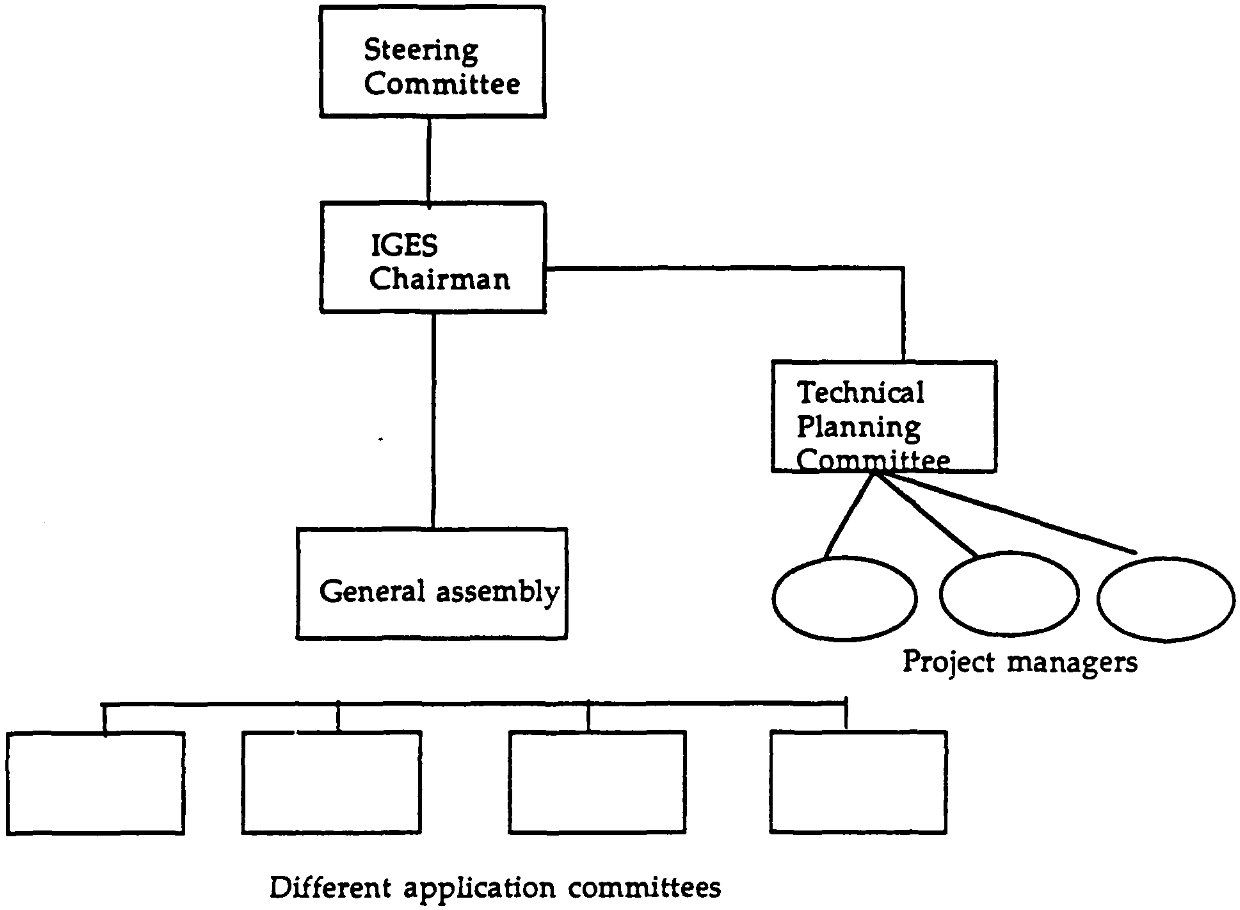
- Development of a standard for product data exchange meeting the needs of US and international industry and government (STEP). The base for this standard is PDES 1.0

3.1.2. Organization of the project

The IGES organization is composed of 700 members from more than 250 different companies. Officially,110 members are working on the PDES project. These members are mainly in the aircraft industry or related activities.

The IGES organization is composed of a series of committees dealing with the development of the specification, the coordination of the planning and the tracking of the projects. A steering committee provides policy and procedural review. Figure 3.1 describes the structure of the IGES organization. The steering committee sets goals and strategies for the IGES organization and provides for policy and procedural review of its activities. The IGES chairman is helped in planning and coordination of the technical activities by a technical planning committee. The technical activities are organized in technical committees. The number and organization of these committees change frequently with time in order to meet the needs or priorities of the organization. Subcommittees or task groups may be added to the committees by appointment of the chairman of the committee.

The organization manages the IGES and PDES project. Since the start of the project in mid 1984, the IGES organization worked very closely with the ISO/TC184/SC4/WG1 committee. In fact the chairman of the IGES organization is also the chairman of the SC4 committee and 90% of the effort on the STEP project is done within the IGES organization. There are usually for PDES general meetings per year. The last meeting was a joint PDES and ISO/SC4 meeting and was held in April 1987.



IGES ORGANIZATIONAL CHART

Fig. 3.1

3.1.3. Presentation of the PDES technical committees and their objectives

For the PDES project, the organization in technical committees corresponds to the different layers of the ANSI/SPARC schema.

At the application level,There are five committees corresponding to the different applications to be integrated:

The mechanical product committee

The aim of this committee is to provide a single information model for the mechanical product area that covers the viewpoint of a typical product life cycle. The model "will probably reside in more than one volume when complete and this may lead to the restructuring into separate models. The links with electrical products and finite element modeling implies that these various applications must be coordinated and produced in a similar format and with consistent cross reference when needed"

The short term goal of this committee is : " to capture the data that is currently incorporated in or inferred from the drawing in an ambiguous form.

This data includes geometric definition and tolerance, parts listing and where-used information, configuration control, design characteristics, requirement and process specifications, interface requirement for components of assemblies and varied views of assembly hierarchy" [ISO, 1987].

The electrical product committee

This committee intends to produce information model of printed wiring board that covers both schematic design and physical design and is expected to be applied to integrated circuits.

The modeling work is carried out by the CAL POLY task team in cooperation with the IEEE. The CAL POLY task team is a joint effort of the IEEE, the California Polytechnic University and PDES to develop a conceptual model of data of electrical products. One of the prinipal efforts of this team is the review of the model by diverse group of industry, government and representatives. A review consists in 'walk-through sessions' where the model is presented, discussed and then updated.

The Architecture,Engineering and Construction (AEC) committee

This committee differs from other committees since it includes several applications mainly architecture, engineering and construction. the initiation

activity reports stated that it has completed a model for distribution systems for heating,ventilating and air conditioning and is developing a global model for building, landforms and process plant. In addition, the AEC committee is developing model representing tabular data, network data and enclosed area data.

The Drafting committee

The committee is developing an information model for tolerance within the context of the design and manufacture of mechanical products. Presentation characteristics including information such as arrow orientation, witness line, text height and dimension precision will be added acknowledging that graphical representation is separate from its information content.

Finite Element Modeling (FEM) committee

Finite element modeling is the description and the prediction of the behavior of an object given its geometry and the external constraints such as loads or temperature. The description is based on the mathematical model of the object. This mathematical model is a discretization of the object into simple finite elements such as beam and membrane plate for stress analysis. The behavior of each element is described by a set of functions such that the continuity of the variables describing the behavior is ensured [Peerey, 1982].

The objective of this committee is to generate a complete information model for finite element modeling which will include s sub-model dealing with the application specific analysis or post processing of the finite element model.

There are four constituent technical areas committees that are supposed to cut across several areas and help generate generic entities for the integrated model:

manufacturing technology committee

This committee is supposed to produce information models that encompass manufacturing aspect of administrative data, mechanical product and tolerancing.

It is supposed to supply information model describing information found on the engineering drawing related to administrative,review the mechanical product to see if it satisfies the product definition requirement according to

manufacturing needs and an review and respond to comments on the information model for tolerance data.

There have been few activity going on in this committee.

Solid modeling committee

Its objectives is to provide a constructive solid modeling (CSG) representation and boundary representation solid (Brep) model. Brep is the description of an object through topological entities such as vertex, edge and. CSG is the description of a part through geometric primitives such as sphere, cone, revolution solid etc.. CSG models are built from boolean trees with the defined primitives as elements.

The two other committees are curve and surface modeling and presentation data committees.

Logical layer committee

A logical layer committee is supposed to:

- formulate and document the methods used in the PDES development.

-integrate the different application models and develop the conceptual model

-develop with the physical layer a specification language (EXPRESS).

Physical layer committee

A physical layer committee responsible for the final physical file structure output

Software support committee

It supports the development in software binding, prototyping and testing, implementation aids and IGES/PDES conversion

3.1.4. The PDES initiation effort

The first step in the PDES project was the PDES initiation effort. This effort has been defined as a proof of methodology and concept with the purpose of defining the methodology and its practical orientation. The PDES report on the initiation activities justifies this effort by the difference between IGES and PDES scope and conceptual approach. The objective is principally to gain experience with this new approach.

This initiation effort was composed by two tasks. The first task was to establish the three layers and a path of communication between them. One specific application model is developed.A schema was developed supporting a mechanical product application a wireframe geometry model and a presentation model. The second task was to illustrate that the logical layer model could be expanded as the need arose, thus other applications were incorporated. For this task two 3 application model were further developed as well as the global model where topology associativity was included.

For the specific application models, *NIAM*, *IDEF1X* and other languages were used. Models using a language other then NIAM had to be translated to NIAM. The modeling language for the global conceptual model was NIAM. which was conveyed to the physical layer through a data description language (EXPRESS).

The initiation activities ended by march 15,1986 by a report describing the work, the lessons learned and the recommendations. and a plan for establishing a working integrated model by September 15,1986.

3.1.5. The Acceleration plan for PDES

In the September 1986 IGES meeting, the steering committee recognized that the project has to be accelerated in order to stay within the planned schedule and decided for a conceptual approach for the acceleration of the project.

The committee considered that the project management depends on three variables: the schedule, the physical and human resources, and the scope of work. For each variable, the committee studied the different options available. It then considered the effect of the options on the timing of the project and its overall success. For example, considering the variable resources, one option is to increase the manpower, since the IGES people constitute the best available people for this project and the project is quite complex. The cost of training will likely to have a negative effect thus the option was rejected.Another option was to narrow the scope by integrating the model that were ready or matured by this time. This option was rejected based on the assumption that all parts were needed for a useful and acceptable model.

Finally, the chairman of the IGES organization considered that

"The only choice seems to be working the tasks of 1987 in parallel, rather than in series. That is, while the specification is being reviewed and evaluated via trial implementations, work can continue on completing the models. It is required only that models be complete at a high level so that they can be integrated. It is not necessary that they be complete at the lowest level. "

It was proposed that by April 1,1987, a model with a functionality of current standards where all parts are represented will be presented as a first working draft.

In reality, only 15 peoples really committed all their work to the PDES project. However, with the advancement of the IGES standard the 700 people are more and more committing their work to PDES. In fact, the chairman of the project declared in the last meeting that 90% of the work done by the IGES organization is aimed toward PDES.

3.1.6. The April 1987 meeting

In April *1987*, the *IGES organization held a joint meeting with the* ISO/TC184/SC4/WG1 group on the PDES/STEP standard.

While the PDES plan expected the integrated model to be ready, several application models were far from complete and the model presented by the logical layer was not an integrated model, but several applications model grouped and translated in the same formal language. Furthermore, several models did not use at all the results and models of the initiations activities.

During this meeting, a redefinition of integration in the light of the "weak " results was a major concern. Expressing this need, a planning committee which has been created in 1986 held several meetings where a discussion about a more structured approach to the organization of the integration through a planning model for integration was discussed and refined.

During the meeting of different committees, there was both a general discussion on the issue of integration and on low level small details issues. These small details discussions were sometimes really time consuming.

3.1.7. The April 1987 plan for integration

As the result of the important difficulties in integrating the information models of each application, the chairman of different committees recognized the need of a methodology for orienting and simplifying the integration process.

Consequently, a method defining the process required for integration was presented during the first plenary session of the meeting.

Figure 3.2 and 3.3 gives an overview of the process.

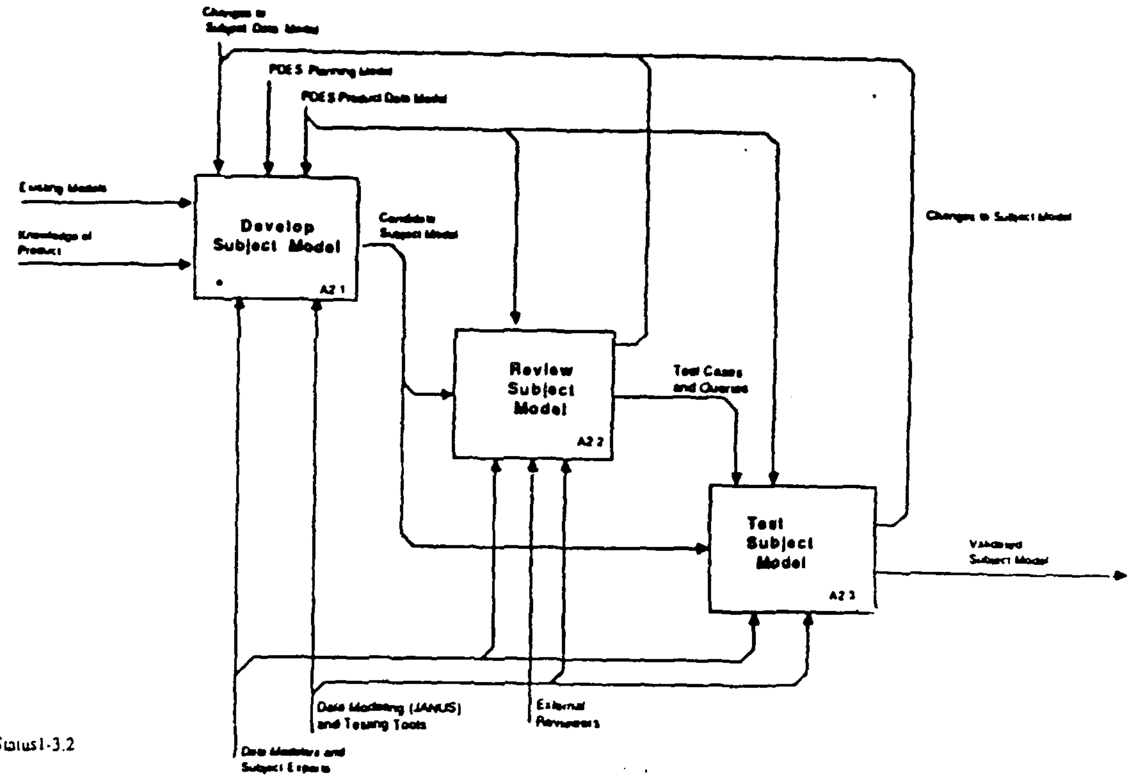
The process is divided in four major activities which are further divided in sub-activities. Each activity has a set of input from other activities and links to the outside world.

The first activity is to develop a strategic PDES product data planning model as an aid to planning incremental development. this planning model essentially defines a global and strategic view of the different applications models and It establishes a higher level relationship between the different application models.

An informal plan defining some steps of integration was presented later in the meeting. The plan consider the integration as an iterative process where the first step is to divide the data relating to an application reference model into internal and external data. This split is a recognition that the model is related to the outside world and that consequently,when the model is generated, there are some assumptions that are made about the outside world. The different assumptions are constraints from the outside world that should be analyzed and surfaced. These assumptions should then be reconciled with the reality of the outside world

The second activity is the generation and the validation of the application models. The models should be validated through a review by external industrials and through building test cases and running queries on the model.

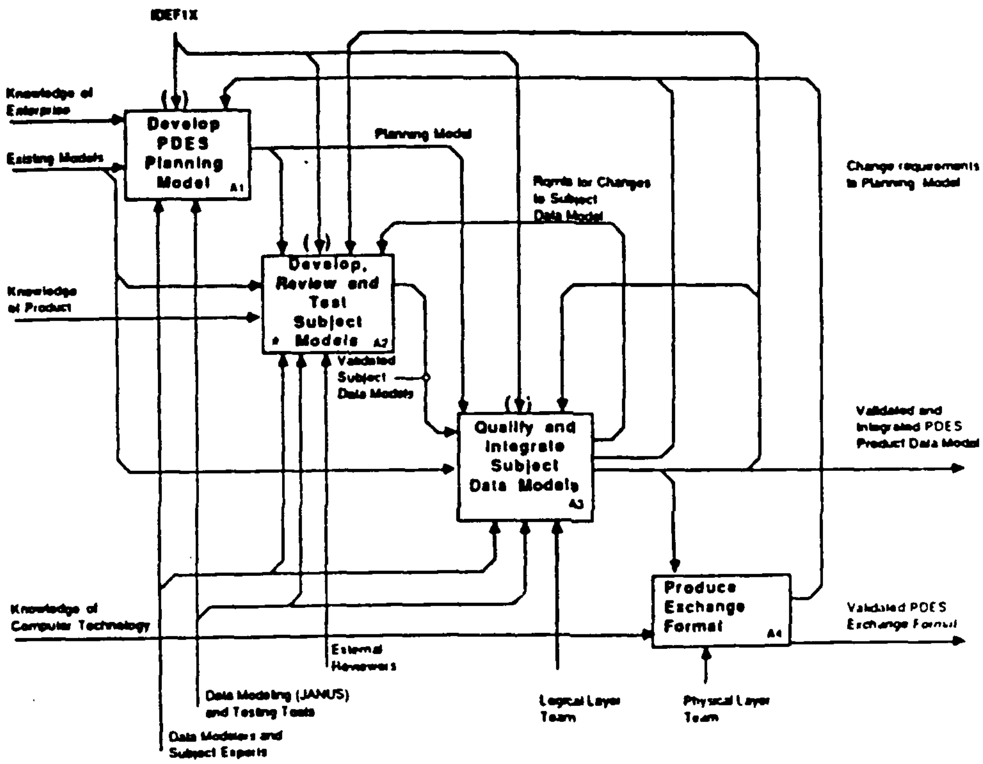
The models are then integrated. The major difference between the process for integration as defined here and the process for integration as defined in the earlier phases of the PDES project is that the integration should occur now at two levels. The first level is the key-based planning model level, that



IntStatus1-3.2

Process of integration for one model (Gale ,1987)

Fig. 3.2



IntStatus1-3.1

Process of integration (Gale ,1987)

Fig. 3.3

is the strategic views of the applications models should be integrated. The second level is the fully defined model.

Integration is needed because there are some differences in the concept of each application. These differences are reflected in the mismatch between the entities and attributes of the different models and integration is the

reconciliation of these different entities and attributes. the integration should not thus introduce alteration on the models.

The integration is then validated through checking if the integration did not introduce alterations on the different reference models.

The validated models are then translated through a data specification language into a physical format. This format also requires validation.

3.2. The Modeling Activities

The architecture of the design methodology is based on the ANSI/X3/SPARC DBMS 3 schema architecture. This architecture assumes that a database management system will be employed by the information processing system.

This framework recognizes three level of abstraction :

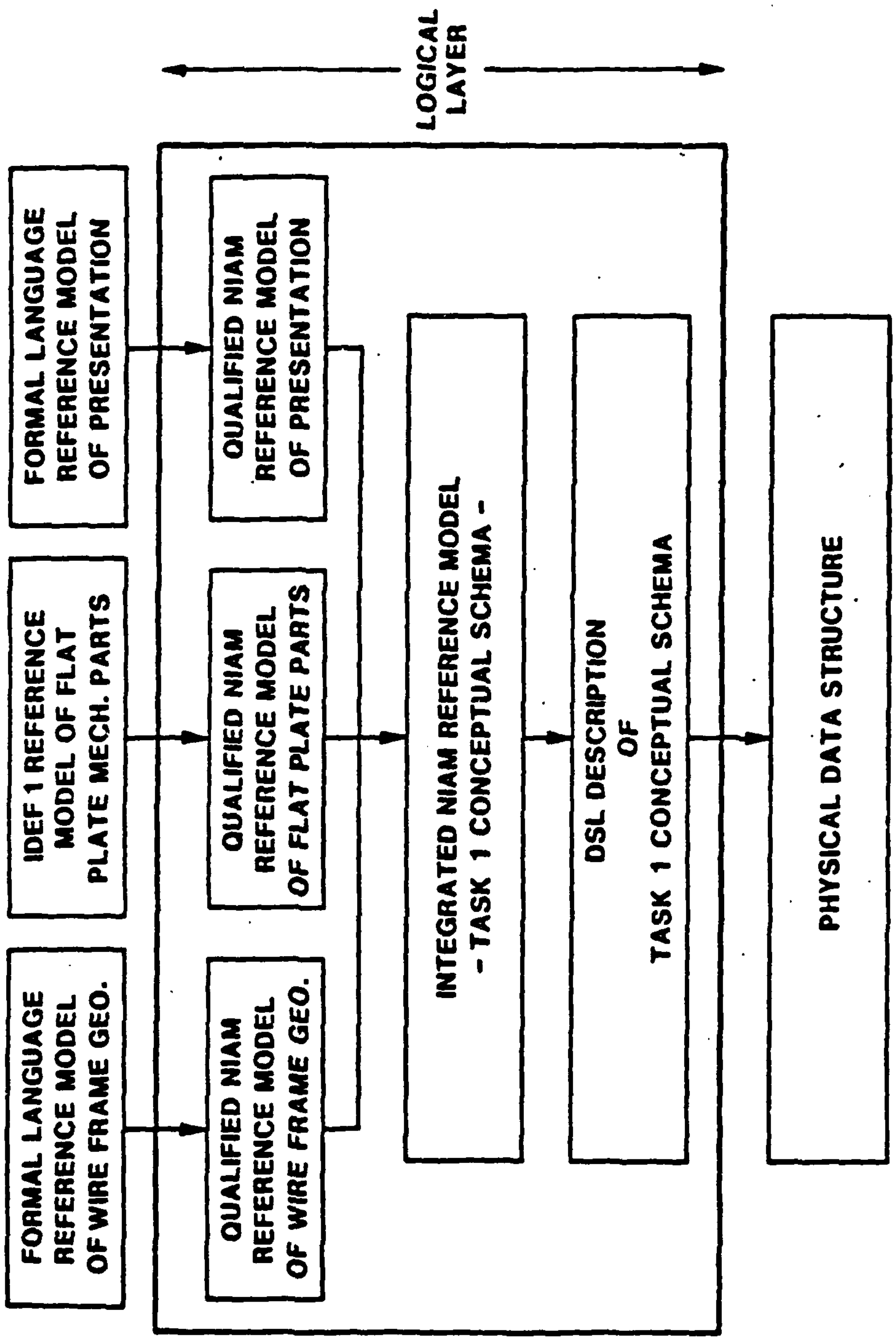
_ a conceptual schema which describes the interface between a real life system and an abstract information base that is to model its states

_ an external schema which describes the interface between a particular user and the information base

_ an internal schema which describes the interface between the information base and its physical realization.

_ The 3 schema correspond to three different views of the data. For example, the view of the data as it is stored in a file is called an internal schema.

Figure3.2 schematically describes the design methodology. There are basically 3 phases:



PDES Initiation Activities

Fig. 3.4

3.2.1. Generation of application models

In this phase, the different application groups define the information entities relevant to their application and an application area reference model is generated. " the application layer models consist of reference models which are a system independent view of information used in the real world. These models encompass a wide range of applications and in principle all use of information. *The intent of the application modeling is to model the real world concepts in term that allow capture, exchange and archiving of computer usable information about them. The development of application reference models is a requirement driven process not a capability driven process"*_ [ISO, 1987].

Several modeling techniques and several languages such a NIAM, IDEF1X, and VHDL have been used

We describe in the following the different steps in modeling used in the electrical model.

- The model scope and context is defined: model of the basic structure of the data which defines the functional characteristics of an electrical or electronic product in the terms of a chosen technology. The stage in the life cycle of the product as well as the functional characteristics on which the modelers should focus is chosen.

- Different definitions of the entities and business rules related to these entities are defined(example:a functional unit may contain other functional unit as components or a functional unit has 0,1, or many functional defined output signals)

- IDEF modelisation is performed : definition of the relationship, keys for each entity then definition of non key attributes, normalization and final refinement of the model is performed

- Several groups involved in different areas of electronic and electrical products are invited to discuss and debug the model. Thus the model is further refined and this step constitutes a verification of the conceptual model.

3.2.1.1. Conceptualization and integration

This phase aims to build a conceptual model which cuts across all the applications. It should describe meaning common to many area subject. It should be used as a resource for developing a conceptual dictionary tool to hold the components of a conceptual architecture.

Specifically some of the steps composing this stage as defined in the beginning of the project are:

- Development of a set of entity categories using the models defined in the first phase as well as input from PDDI

-Development of a set of generic entities, generic structures(an organized set of interrelated entities that are common to several applications) and application specific structures

- Partitioning of the application model into generic and specific structures.

- Development of a conceptual tool to hold the different structures

- Definition of the mapping between the different application models and the global model and the recording of the mappings in the dictionary

_ Verification of the recoverability of the original appiication from the global model and further adjustment of the model as a result of the verification.

3.2.1.2. Integration during the initiation phase

We provide in the following an example of the actual use of the methodology during the initiation phase of the project for the electrical application model:

- literal translation of the application model to the modeling language used for conceptual modeling (Nijssen Information Analysis Method (NIAM)in this case).

-Iterative adjustment of the model through discussion of the model between application and logical layer. The resulting model is considered as qualified.

-replacement of the specific objects in the qualified model with objects considered as generic from the resource model (geometry, presentation and topology objects)

- attempt of reconciliation between the qualified model and the global model by an informal mapping based on English sentences

We can remark that the most important phase here is integration and in this case what was basically done is the replacement of 10 to 20% of specific objects in the qualified model with objects from the geometry, presentation and topology model.

3.2.1.3. Integration phase for the PDES draft 1.0

The logical layer committee considered that the models generated by the different disciplines were not good enough for integration. As a result of the time constraint, there was no iteration between the application modelers and the logical layer committee.

There was no replacement of specific entities by generic entities like in the initiation activities since no overlap between the different applications was found. what practically happened was a translation of the different models into the EXPRESS language and the writing of common data structure for points and lines. (during all the activities EXPRESS evolved dramatically responding to the needs of the different needs and remarks of the application layer).

Rules of business, English explanation were generated in order to help the testing of the model by external parties and allow the application layer to check the mapping between their model and the EXPRESS model for further refinement.

3.2.2. Post conceptualization

The aim of this phase is to convert the conceptual global model into a grouped logical record form. and then formulate a physical file structure for PDES described by a formal language.

The first phase as done in the initiation activities can be broken in two basic steps:

_ Grouping of the model through an informal "definition of relationships"

_ Translation of the group into a data specification language (EXPRESS in this case)

For the second phase, two language-baed exchange formats with context free grammar were used as a base for the PDES neutral format : PDDI format and LBEF (Language based exchange format)

3.2.3. Presentation of the conceptual tools

NIAM

Nijssen Information Analysis Method is a binary data modeling method using a graphic language for describing information. It was developed in Europe in 1972 and was originally oriented to databse design. NIAM started as a method to to define a conceptual schema. The authors of NIAM [Falkenberg and Nijssen, 1982] define a conceptual schema as :

> a description of a problem which would specify or prescribe exactly which information one is interested in, and this in terms which were completely independant of computer implementation aspects.

NIAM has been gradually enhanced to include business analysis and process analysis as well as software generation and implementation. However, NIAM places more emphasis on information analysis than on process analysis.

NIAM is based on five principles:

- All traffic between a user and an information system consists of a natural language sentences.
- There is one grammar called conceptual schema which completely prescribes all the permitted states and transitions of the database.
- There is an internal schema which prescribes how all the permitted states are to be transformed into physical data.
- There are external schemas describing the view of a user of a database. The conceptual view is based on deep structure natural language sentences while the external view have a different representation such as Codasyl records or normalized relations.
- All three schema can be considered as a database.

A conceptual schema consists of a set of Sentences Type or Facts Type which are business rules of the real world that are divided into Ideas and Bridges, Non-Lexical-Object Type (NOLOT):fundamental categories of the real world

divided into two kinds concepts (somewhat corresponding to entities) and symbols (attributes), subtypes of NOLOT which are generalization of links between object types, Lexical Object types (LOT) and constraints. NIAM is a very developed language for describing constraints. There are several classes of constraints such as uniqueness, equality, exclusion and cardinality. Furthermore, NIAM distinguishes between integrity constraints which are rules containing knowledge of valid systems and transitions and query constraints which are all legal queries or processing access to knowledge.

NIAM uses information flow diagram for describing information. an information flow diagram consists of a set of processes, user input, data bases, conceptual schema and information flow.

IDEF1X

IDEF stands for Integrated Computer Aided Manufacturing Definition and is a set of three modeling methodologies for describing manufacturing that have been developed under the USAF ICAM project. IDEF1 is a "method used to produce an information model which represents the information needed to support the functions of a manufacturing system or environment. It is a reflection of the total manufacturing enterprise and provides a baseline definition of that organization's information needs". The other two methods are: IDEF0 for for representations of the function of a manufacturing system and IDEF2 for representing ht e behavior, information and resources of a manufacturing system. IDEF1X is the latest version of this method.
IDEF is a language with syntax and semantics for expressing a data model plus a discipline for developing the model. It is founded on an extended Entity Relationship model. The language is based on diagrams for representing the information and a dictionary for storing the meaning of each element in the model. The discipline is a a series of steps beginning with definition of the areas of the enterprise of interest and continuing through a series of specific refinement to a fourth normal form relational model.

The development of the information is seen as a cyclical activity with a data collection, validation and acceptance cycle. The integration plan proposed during the April 1987 meeting (fig. 3.3) is an example of such an activity.

EXPRESS:

EXPRESS was originally defined as a data specification language created by Doug Shenck who is the Chairman of the logical layer committee.It is a declarative language used to express an information model. His author defines it as:

"its purpose is to capture the meaning of data so that the provider and the receiver of data may interpret it without error. It is not a database tool". Its most important conceptual notions are : Entity (object,concept or idea that has meaning to the UoD), Attribute (fact about an entity or data from which facts are derived), Class(collection of entities), a Rule(constraint to be enforced by the information system), Operation (how an entity is to be used within the enterprise), a function and procedure. The last three types have been regrouped as kinds of Algorithm.

EXPRESS has dramatically evolved and is now both a conceptual schema language and a data specification language. The recent definition of EXPRESS is: " the objective of Express is to communicate what is known about information from the earliest stage of abstract thought to the implementation of data in a database." [ISO, 1987]. For this purpose, EXPRESS has two components :

- An Abstract Schema which "define entities such that they are independent of the way a database is constructed" and "capture the UoD view about the character and behavior of entities".

- A Concrete Schema which " addresses the problem of tailoring those entities that appear in the Abstract Schema so that they may be used in a known environment for a specific application". All the information needed for defining the physical schema should be present in the concrete schema.

In contrast to IDEF1X and NIAM, EXPRESS does not use graphics for representing information.

3.3. Validation

Few work has been done on Validation during the initiation activities, Validation was done only at the level of the informal mapping between the logical and application layer for some applications when the IDEF1 model was translated to the NIAM language.

Validation is an important problem that came out during the April 1987 meeting. The committee on implementation and testing was unable to come out with any solution for checking the consistency of the different models. The origin problem at this level was recognized as coming from the lack of technology and practical methodologies for consistency checking.

3.4. SUMMARY OF the Problems encountered in the PDES process.

During the development of the project, there are some major problems that do not constitute specific problems to the PDES project but that are more general to other standards and to some extent to the design of information systems in an integrated environment. We present in the following these problems which constitute the basis of the definition of a methodological approach to standard for data exchange in an integrated environment that we develop in the next chapter.

Inability to meet the schedules

Despite the several efforts that have been done to accelerate PDES development, PDES is well behind the schedule. Several application committees models and especially the electrical and mechanical reference models which are the most important models are far from complete. During the April 1987 meting, several members of the international community criticized the project on this basis. For instance, the french representative remarked that "as far as he is concerned, the game consisting in promising that the models be ready for next year is going to last".

difficulties in organization

The chairman of the electrical committee raised a major concern about the organization and The coordination in order to obtain the integrated

conceptual model. This concern was shared by the majority of the participants.

The integration of the different models is presently done by one or two persons and several participants in the April 1987 meeting consider that an organization with more sharing of the responsibilities and different distribution of the tasks is needed. Some participants criticized the configuration management of the project and strongly expressed their need for a better configuration of the project.

Poor conceptual modeling

The major concern of the April 1987 meeting was the weak results obtained at the level of the integration of the different conceptual models.

Since the beginning of the PDES project there have been essentially two major effort for integration of the different models:

- the first effort was during the initiation activities. It consisted in replacing entities in the electrical, mechanical and finite element reference models by entities from the geometry and topology model (these entities are called generic entities).. Only 10 to 20% of the specific entities of each model were replaced.

- the second effort occurred during the last three months. This effort simply consisted in the translation of the different reference models into the Express language.There was no replacement of any entity in any application model by a generic entity. Consequently, there was no integration in the sense that the PDES project has defined.

lack of validation

There are serious problems for defining a method of validation of the reference models. There are even difficulties in defining what is validation and what should be validated.

4. ANALYSIS OF THE PROBLEMS AND PRESENTATION OF THE METHODOLOGIES

4.1. Technical problem and solutions for PDES

The important difficulties in integration of the different application models made all the participants in the recent PDES meeting stress the need for a better defined methodology in order to provide the integrated model and a redefinition of integration.

We think that there is a serious flaw in this approach toward a conceptual model, and in the following we provide, an analysis of this flaw through different comments of the participants in the April meeting and an object oriented methodology for conceptual modeling. This methodology provides also a method for the problem definition and decomposition phase of the design of PDES.

4.1.1. Analysis of the reasons forthe difficulties in generating the integrated model.

4.1.1.1. Embedded assumptions in the models

During the April meeting, the chairman of the logical committee said that he had difficulties in understanding the models presented because he found that embedded in the models are several assumptions and business rules that seemed to be obvious to the modeler and that were not obvious for him. He added that not making explicit the assumptions reduced the clarity of the models and increased the difficulties for integration.

We mainly distinguish two type of assumptions : different views of the product to model and different contexts and realities in which it is defined.

5.1. Different views of the product reflected in the model

The representative of Germany at the April 1987 meeting who had previous experience with the integration of models from different disciplines

attributed the difficulty of integration to the fact that different concepts are referred to by the same term in different application information models .

For instance, the term <u>tolerance</u> is used both in the drafting discipline and the mechanical discipline . In the drafting discipline , it is defined as " an allowable variation of the physical form shown as part of a <u>dimension in the drawing view.</u> In the mechanical discipline, it is defined as an allowable deviation of the <u>geometric aspect</u> of a product from its design nominal geometry . Furthermore, the working document that describes the model specifies that pictorial representation and dimensioning practices are excluded form the scope of the model.

While the two disciplines have similar definitions of tolerance, its attributes in the two disciplines are totally different and tolerance is viewed differently as shown in Fig. 4.1 and Fig. 4.2 .

The same difficulty was recognized by other members of the mechanical model committee . For example, a modeler remarked that if we consider the model from the structural point of view, a certain set of attributes is generated for an entity but if we consider the same model from the thermal or the material composition point of view, a different set of attributes is generated.

The AEC and mechanical models also provide examples of how an entity that is viewed differently may result into an ambiguity during the process of integration . Both the AEC and the mechanical model contain the entity item. However, when the models were compared, the modelers found that the semantic meaning of the two entities was different. For the AEC modeler, an item is a part. For the mechanical modeler, it may represent a part or an assembly. Moreover, the attributes of an item differ if they are considering a functional description, a technical description ,a technical information about an item, or the item as a product ready to use.

These examples show that the model depends on how the modeler views the part or product to model and that the use of several views that are not explicitly defined makes the model complicated and ambiguous.

5.2. <u>Different contexts and realities reflected in the model</u>

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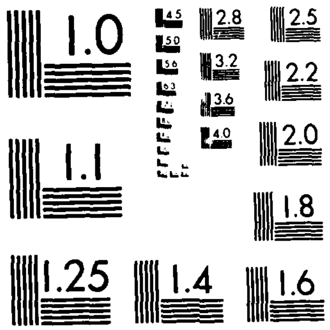


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ISO TC184/SC4/WG1 Tolerance Model	DOCUMENT 3.?.1.6 (Working Paper)	9 JANUARY 19..

Tolerance Entities

---

(402) Geometric tolerance

A geometric tolerance is a class of entities:

```
ENTITY Geomtric_Tolerance : subtype(Angularity(406),
                                    Circular_Runout(407),
                                    Circularity(408),
                                    Concentricity(409),
                                    Cylindricity(410),
                                    Flatness(411),
                                    Parallelism(412),
                                    Perpendicularity(413),
                                    Position(414),
                                    Profile_of_a_Line(415),
                                    Profile_of_a_Surface(416),
                                    Straightness(417),
                                    Total_Runout(418));
```

Propositions:

Each Geometric_Tolerance(402) -

- is a Tolerance(400).

- may be an Angularity(406) tolerance.
- may be a Circular_Runout(407) tolerance.
- may be a Circularity(408) tolerance.
- may be a Concentricity(409) tolerance.
- may be a Cylindricity(410) tolerance.
- may be a Flatness(411) tolerance.
- may be a Parallelism(412) tolerance.
- may be a Perpendicularity(413) tolerance.
- may be a Position(414) tolerance.
- may be a Profile_of_a_Line(415) tolerance.
- may be a Profile_of_a_Surface(416) tolerance.
- may be a Straightness(417) tolerance.
- may be a Total_Runout(418) tolerance.

- must be one of the listed tolerances (406-418).

<u>The entity "tolerance" in the mechanical application</u>

Fig 4.1

117

Tolerance

Allowable variation in the product's physical form. Shown as part of a dimension in a drawing view.

In Express

```
ENTITY tolerance;
  positive_variation : real;
  negative_variation : real;
  (* What about the case where it can only have one direction? *)
END_ENTITY;
```

Used on page 17.

The entity "tolerance" in the drafting application

Fig 4.2

During the process of integration of different discipline reference models, the modelers found that each model reflected different business practices that were not explicit and the integration plan recommended that the application committee modelers make an effort for surfacing these assumptions. These business rules reflect a context in which the product is designed or manufactured. The integration of models reflecting different contexts has been quoted by the logical layer committee as " a non-trivial task".

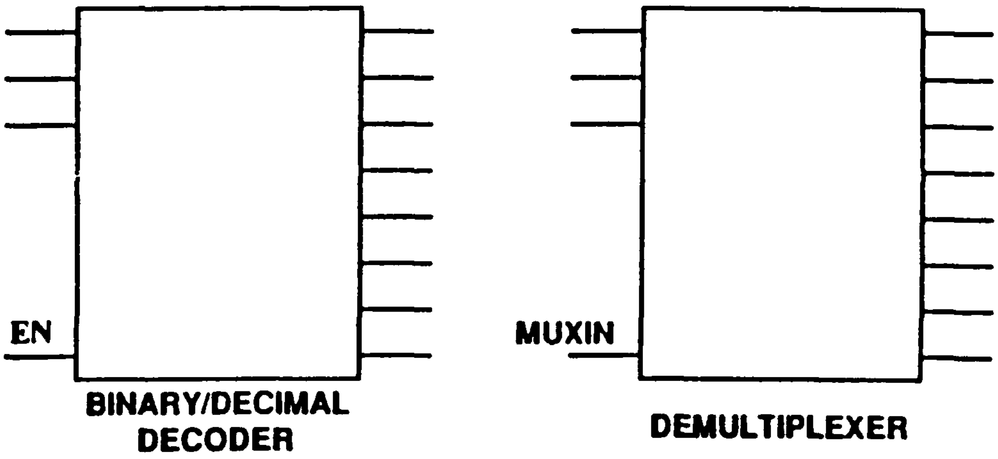
As an example of the ambiguity resulting from a non explicit context , a question as to whether or not an item as it is made, as it is planned to be made or as it is used should be considered as the same item was raised in the mechanical committee during the April 1987 meeting. For example, if a wheel is designed to support a temperature of 300^0 c , the wheel, but after being manufactured supports only a temperature of 100^0 c, should the wheel as it was being planned to be made and the wheel as it was manufactured be considered the same entity. If this wheel is used in a car, this wheel can be either the right or the left wheel of this car. Because fiction wears them differently , a right wheel ultimately would have a different function from the left wheel . They thus may be considered as different entities in the context of use while in the context of manufacturing, the two wheels are the the same object. Hence the same term can refer to different objects.

Confusion can also be caused when same part is referred to by different terms in two different contexts. For instance, an integrated Chip (IC) is called binary-to-decimal decoder because of its function as designed and is also referred to as demultiplexer as-used. Moreover, it has a number 74LS138 in the technical documentation. Conversion is needed in order to imply that the same part is involved.

4.1.1.2. Discussion of the difficulties

We consider that the main origin of the difficulty for integration is the different assumptions , beliefs, and business rules that are embedded in each model. The assumptions that are embedded in a model have for origin a

74LS138



SAME PART USED DIFFERENTLY

CAL POLY TASK TEAM
28 FEB 87

Fig 4.3

limited view or set of views from which the modeler sees his model and the modeling of the context in which the object to model has been produced.

Consequently,if an application model reflects one set of views, and another application model reflects a different set of views then it is understandable that no integration can be obtained since the logical layer modeler would have to find common entities between two models of different nature. It is mixing apples and oranges ! . For example , the electrical application model reflected a functional and schematic point of view while the mechanical product model did not reflect these views but considered other views such as process or structure views. Integrating the models in the sense of finding common entities at this stage does not make sense.

In the current state of affairs, the application committees are generating and will generate reference models of their application but not models to be integrated. In other words , the electrical application committee may eventually come out with a model that describes perfectly a printed circuit board and the mechanical group one which perfectly describes a plane. However, these models are difficult to integrate since they are describing totally different approaches to a product and correspond to different contexts and realities. They do not correspond to the concept of a product developed and produced in an integrated environment.

In order to integrate in this sense and in the present state of PDES , the modelers at the logical layer need to understand the different views and contexts embedded in each model, extract the part of the model corresponding to the views that are common to the applications, and to integrate on this basis. This task is enormous and time consuming . In fact, the integration plan proposed during the April meeting try to alleviate the task of the logical layer by asking each application committee for a detailed analysis based on external assumptions.

Different views and contexts in one model also makes the checking of the consistency of this model very difficult. The work of the testing and implementation committee mostly focused on this point. The different members of this committee agreed on the difficulty if not the impossibility of such a task in the present state of the models.

Furthermore, we do not think that integration means only the finding of entities that cut across all applications, that is, finding a set of views and contexts that are relevant to all applications. We also think it consists of finding common entities from a certain set of views in a certain context for the applications that consider these views to be relevant to their domain.

For example, the thermal aspect is relevant to the mechanical and electrical and but not to the drafting application, and it would be useful to generate a sub-model based on this point of view.

The methodology also assumed the generic entities would come from the topology and geometry models . This assumption should not be taken for granted. We believe that there should be a systematic and formalized way of generating these entities.

The analysis of the difficulties in integration for the PDES standard reveal the need for a formalized and organized approach to this phase where the different assumptions of each modeler are formally and explicitly defined. Based on this approach a new *decomposition and modularization of the* problem and an architecture based on the logical life cycle of the product should be defined.

we describe in the following such a methodology and show why this methodology would solve the problem.

4.1.2. Description of the Methodology

The idea of a conceptual model integrating different applications models is the result of a unifying trend to model the whole of the industrial reality through a few universal concepts. We introduce in the following the concepts of view, perspective and context.

4.1.2.1. The concept of view

The specification of products is defined through several descriptions of this product. A view is a description of a specific aspect of a product. Examples of views are: document view, schematic view, assembly view.

At each point of the life cycle of a specific product, we represent the product concretely through different media such as a document as-designed, a prototype as-engineered or the product as manufactured. Each of these realizations is an instance of the product considered as an object. A view instance is the concrete realization of an object according to a view .

Fig. 4.3 shows instances of different views of a NAND logic gate.

The product is constantly modified and improved at each stage of its life cycle. In order to obtain consistency among the different data about the product that flow among design, engineering and manufacturing, it is important to isolate and keep track of those different changes . A view version is the set of view instances of a product at a certain point in time. For example, if a manufacturer decides that the NAND of Fig. 4.4 should be manufactured in one component instead of two component, we have a new version of the NAND. Fig. 4.5 shows the 2 versions of the NAND.

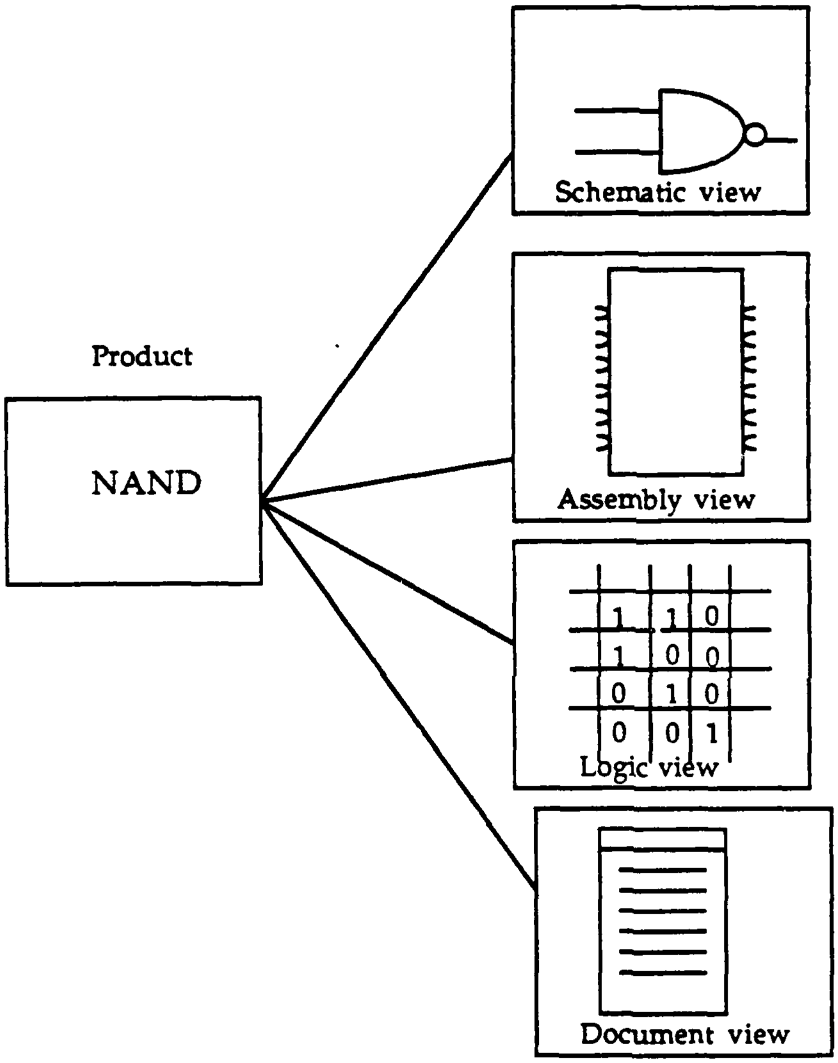
A delta-view captures the modification between two adjacent view versions.

The importance of the concept of version has been in fact stressed by Roger Gayle, the chairman of the electrical application committee [Gale, 1985] :

> After release of a configuration document (document describing the characteristics of a document) Formal procedures and documentation are usually required to alter these documents. The change directive results in specific revisions of one or more configuration document. These change directives are part of product definition.

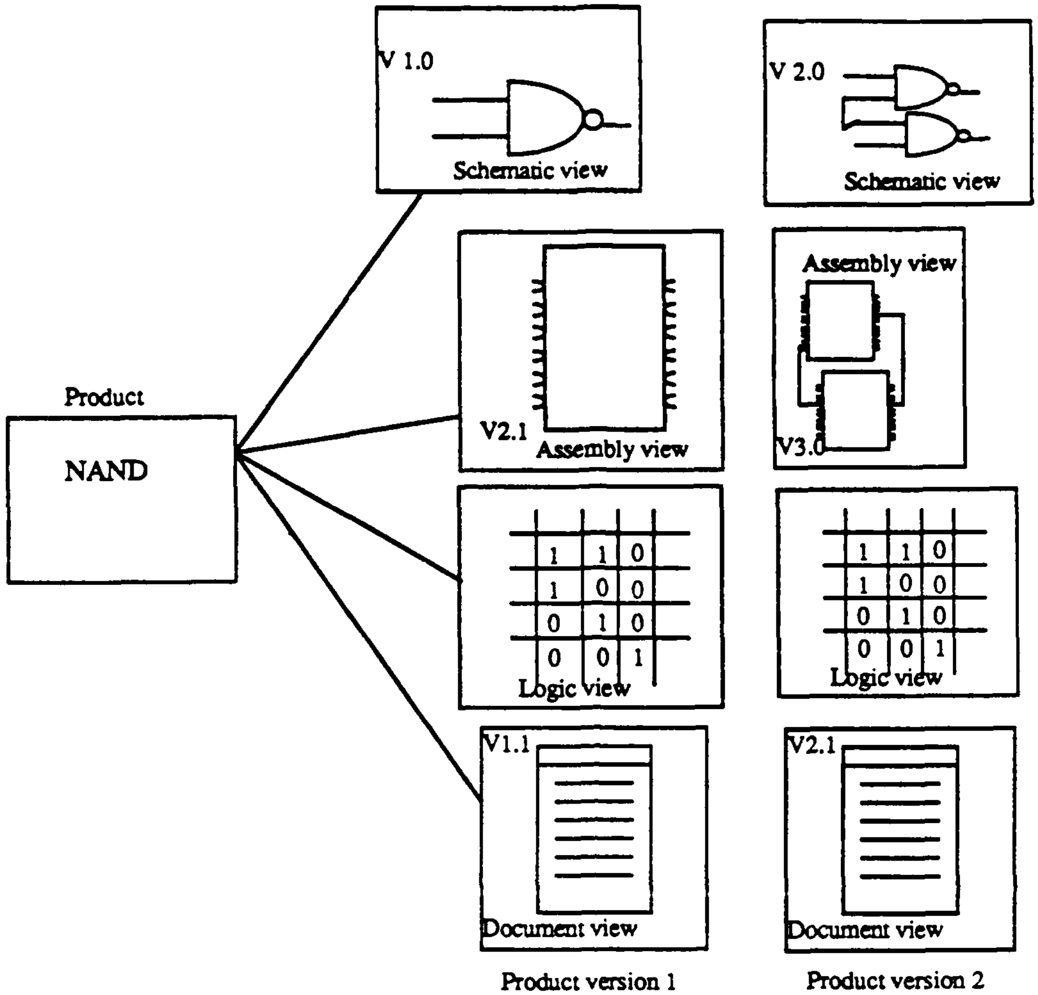
4.1.2.2. The concept of perspective

It is necessary to logically partition the views into separate groups so that the modeling can be decomposed into sub-tasks which are manageable by people especially in complex projects such as PDES .



<u>Different views of a NAND logic gate</u>

Fig. 4.4



<u>Different view versions of a NAND logic gate</u>

Fig. 4.5

Several views overlap with other views . For example, a 3D-wireframe-view and a solid-geometry-view will likely have an important overlap among themselves. On the other hand, these views have few overlaps with a bill-of-material view.

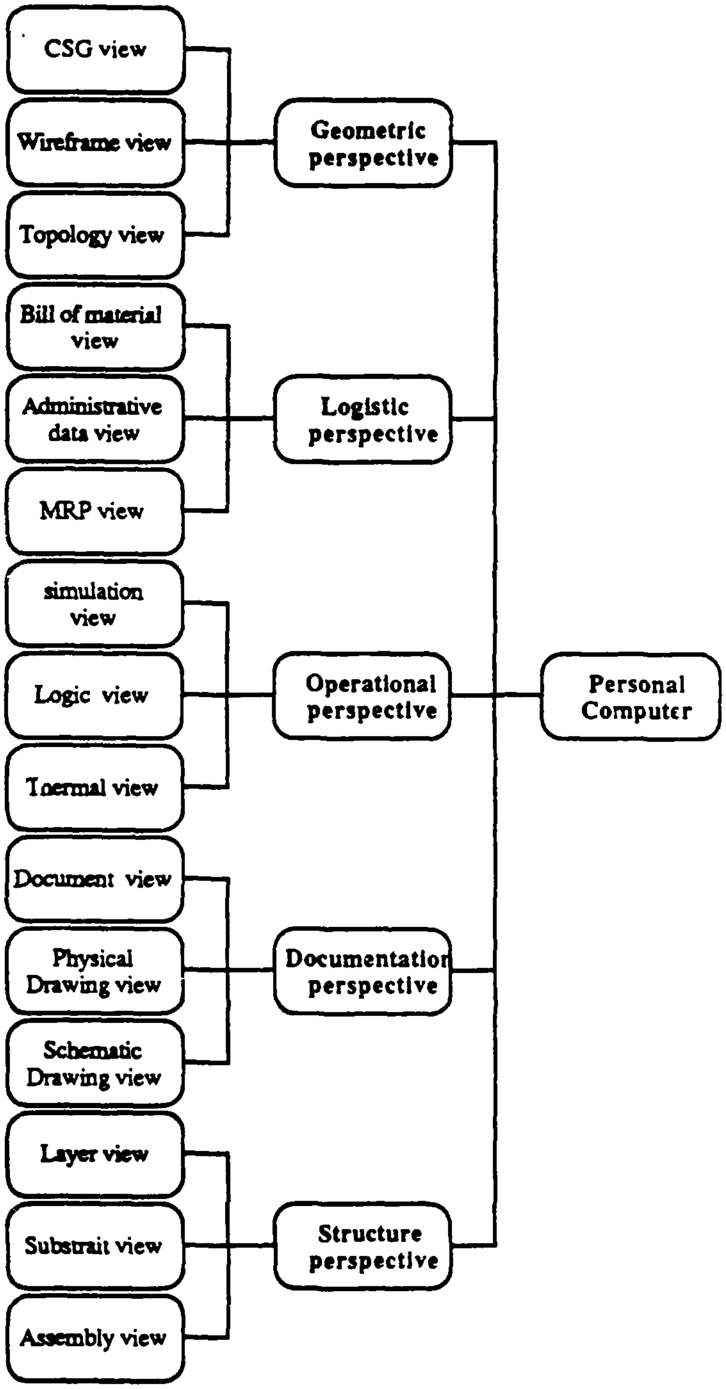
In order to divide the integration into modules that are logically independent, we introduce the concept of perspective. A perspective is a tightly coupled group of views. Different perspectives are loosely coupled so that the validation of each perspective can be done independently of other perspectives. The fact that there are few overlaps among views of different perspectives do not mean that different perspectives are totally unrelated since one obvious relation is that each of the perspectives is a perspective of the same object.

Integration of islands of automation in a heterogeneous environment and control over the design process requires a rigorous formalization of the various descriptions of a product . In the following , we give examples and definitions of some perspectives:

Geometric perspective: description of spatial shape, forms and contours of an object and spatial relation among parts of an object. Examples of views within this perspective are : Wireframe view, constructive solid geometry (CSG) view , topology view, feature view and boundary representation (Brep) view.

Logistic perspective : description of an object for the purpose of generation of operational and strategic procedures concerning the object. Examples of views within this perspective are : bill of material view, administrative data view.

Documentation perspective : set of conventions for pictorial (graphic and text) representation of an object and its behavior and the organization of different representation within a document. This perspective is primarily human oriented. Examples of views within this perspective are : document structure view, drawing view and presentation view.



Example of views and perspectives for a PC

Fig. 4.6

Structure perspective: description of the hierarichal organization of sub-components objects and the relationship among the sub-components. Examples of views within this perspective are : layer view, assembly view

Operational perspective: description of the behavior of an object under the different external stimulus signal and constraints. Examples of views within this perspective are : thermal view, vibration view, simulation view and deformation view.

Fig 4.6 shows an example of some relevant perspectives and views for a personal computer. The different perspectives reflect different 'mental models'.

4.1.2.3. The concept of context

A context is the reflection of the environment of the product. There are several types of contexts. An important type of context is the particular stage of the life cycle of the product . A product goes through several stages such as: design, engineering, manufacturing, testing , maintenance and use. This context is to be explicitly specified during the generation of product data models. We would say, for instance, that a modeler is modeling a personal computer as-designed. As we have seen, if this type of context is not specified, the same product in different contexts may be considered as two different products. Since the different contexts are linked, this interpretation may result in ambiguity and even inconsistency.

There are also other types of contexts. A product can contain components that can be used only for military purposes. In this case, we would distinguish between a military and a civil context. A NAND has different schematic representations depending on wether this representation is based on the ISO or ANSI standard and these two contexts, have to be differentiated. The company in which the product is made is another type of context.

4.1.2.4. The product data space

Each application model describes the product through several perspectives. Each perspective being composed of several views. This description is made in several contexts. We consider that context, perspective and application are different independent and important aspects of the product data model .

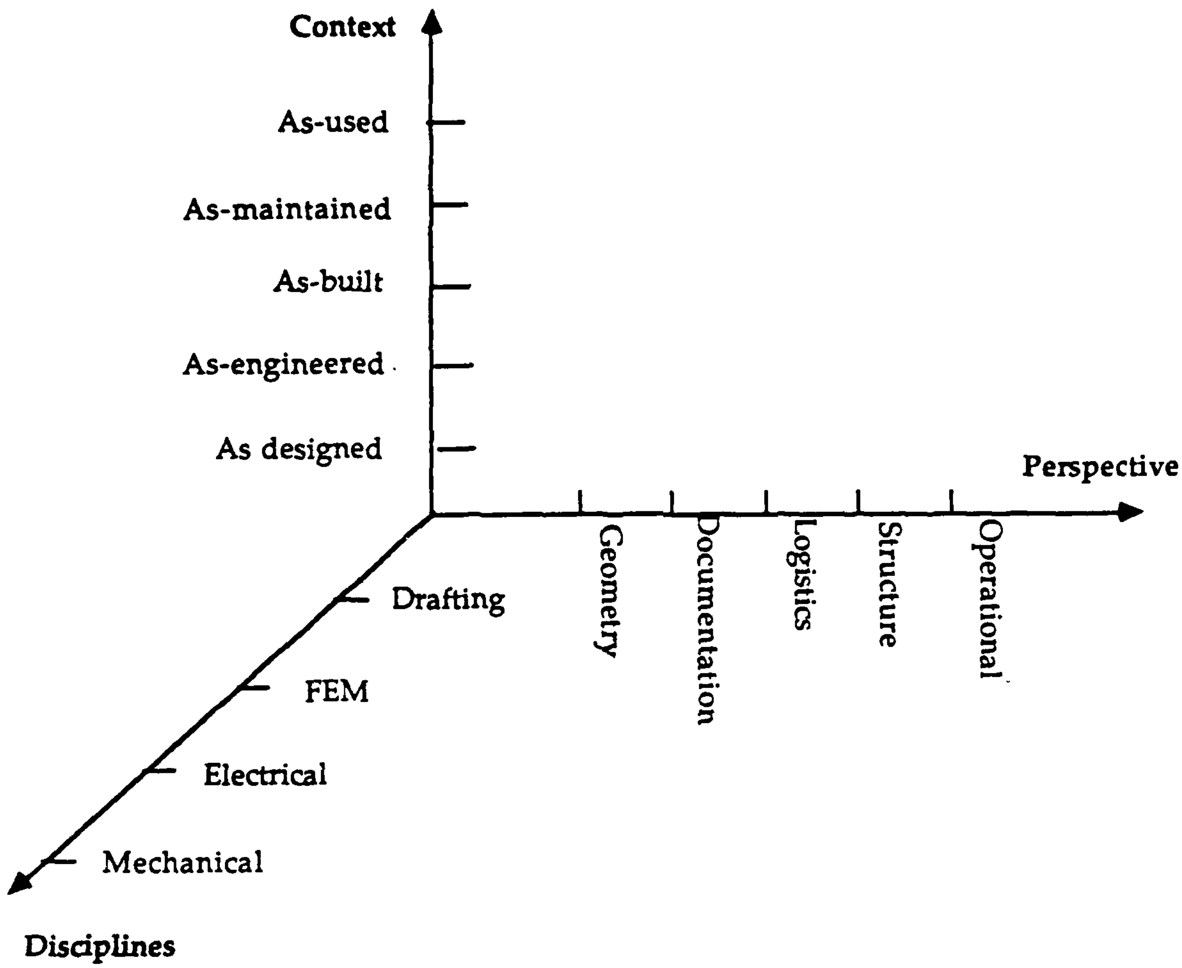
The introduction of the notion of view and context is a way of making explicit the different assumptions that are embedded and usually not explicit during the design. Consequently, in generating a product model each modeler is under this approach consciously modeling through a certain set of views in a certain context.

Fig 4.7 is a representation of the product data space. More generally, the discipline axis corresponds to the different knowledge domains and area of expertise. The perspective axis corresponds to the different schema in a normalized form of the data. The context axis corresponds to the environment in which a product or object evolves and in particular its life-cycle.

4.1.3. Advantages of the approach

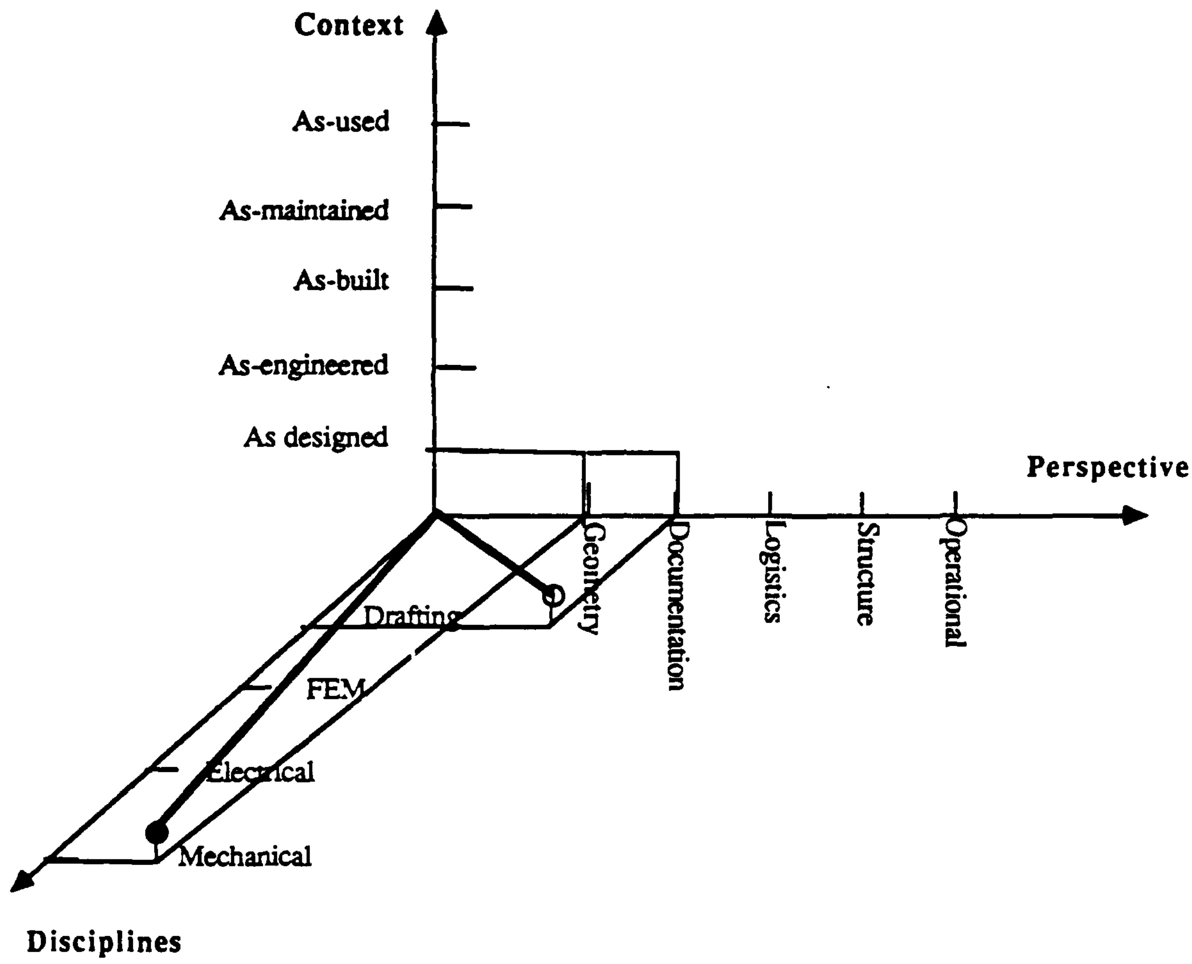
4.1.3.1. Resolution of semantic ambiguity

The explicit distinction among different views and different contexts for the product solves the different ambiguities that we have described in the beginning of the chapter. For example, the term tolerance is ambiguous because it is used by the mechanical applications in a geometric perspective and by the drafting application in a documentation perspective. Figure 4.8 shows the difference using the data product space representation.



PRODUCT DATA SPACE

Fig. 4.7



● Tolerance in the mechanical application

O Tolerance in the drafting application

PRODUCT DATA SPACE

Fig 4.8

4.1.3.2. Resolution of inconsistency or contradiction among different product data

The introduction of the concept of version manages the change of a particular aspect of the model. The result of the modification is captured through the use of view versions. The modification itself is captured through the use of delta views. Only one version of a specific view may belong to a product version. A change in the version of the product implies a change in the different view versions.

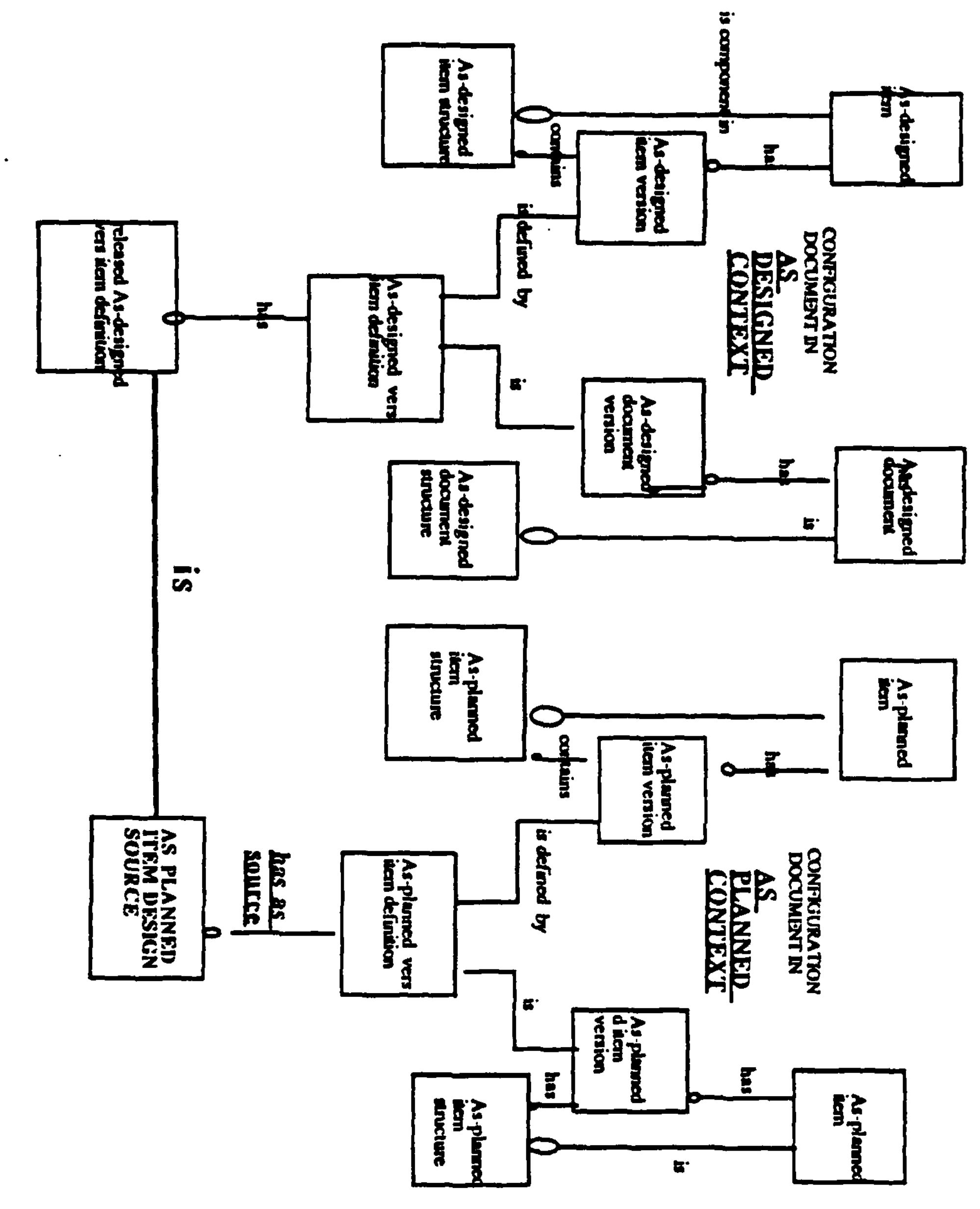
A change in the context of the product is reflected through a change in some or all the views. For example, the design team of a printed circuit board send their product version to the engineering team. The engineering team finds that the as-designed product needs a modification in order to be manufactured. the result of the modification is captured through a new version of the product and new view versions of the product version.

The inconsistency among different product data is solved by the management of the update of the product using view versions.

4.1.3.3. A better configuration management of the data

An important result of the distinction among different contexts and of a formal definition of the links among contexts and among views is the ability to track back the flow of product data, for example, from maintenance to manufacturing and from manufacturing to design .

For instance, Gale Roger, the chairman of the electrical committee [Gale, 1985] distinguishes among an as-designed, as-planned and as-built configuration documents for the modeling of the configuration document . A configuration document is a document which contains all or part of the characteristics of an item. An item can represent an assembly, subassembly, or a part. As-designed configuration documents contain the specification of the designers. As-planned configuration documents are generated in the manufacturing planning process (operation and routing sheets). The as



<u>**Example of 2 contexts and their relationships**</u>

Fig 4.9.

planned document differs from the as-designed document in structure and also in content since frequently, the items can not be manufactured as exactly as specified by the designers. Furthermore, some items vary from the specification of the manufacturers. The documentation of items having acceptable variances form the prescribed limits plus the as-planned documentation constitute the as-built documentation.

Gale is thus distinguishing among three different contexts the as-designed, as-planned and as-built different contexts. The source of an as-planned document is an as-designed-document, and the source of an as-built document is an as-planned document.

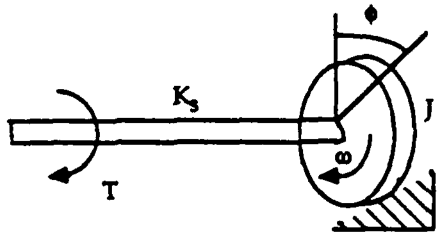
Distinguishing between the two contexts is fundamental during the PDES design development since as Gale points, in order for CIM to succeed, as-designed product data should be successfully captured and transferred in order to generate an automatic as-planned configuration.

Furthermore, the existence of a formalized and explicit definition of contexts and their relationship allows the tracking back of changes in the product. For instance, if a failure occurs during the use of a product, the origin of the failure can be an error in the design, the engineering or the manufacturing. As we have seen in the example of the document configuration, an as-built product model contains data related to manufactutring, engineering and design. The distinction among the different contexts implies the distinction among product data related to each context. Consequently, we can track the origin of the failure and if the failure implies, for example,` a change in the design, we can monitor and accelerate the subsequent changes in the engineering and manufacturing through the links among different contexts.

4.1.3.4. Efficient data processing

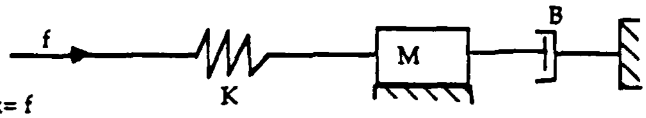
A view is an abstract way of describing a product. Consequently, the description of different objects from one view or perspective may be exactly the same, even if from other perspectives, these products or objects are completely different. For instance, Fig. 4.10 shows instances of products that are completely different from a geometric perspective ; however, from an operational perspective , they are different representations of the same conceptual problem. Indeed, if we use a mapping table, the differential

$J\, d^2\phi/dt^2 + B\omega + K_s\phi = T$



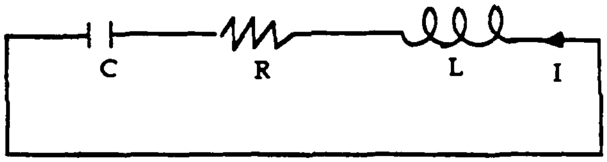
Shaft

$m\ddot{x} + B\,dx/dt + Kx = f$



Force - torque analog

$LQ + Rd\ddot{Q}/dt + Q/C = E$



Electric analog

E Voltage	L inductance	R resistance	1/C reciprocal of capacitance	Q charge	I= dq/dt Current
f Force	M Mass	B Viscous damping coefficient	K Spring constant	x displacement	v= dx/dt Velocity
T Torque	J Moment of inertia	B Viscious Friction	Ks Torque constant	ϕ : rotation angle	ω rotation velocity

Mapping Table

Different Representations of A Shaft

Fig 4.10

equations expressing the behavior of each product under external forces or signals are exactly the same. The simulation of an electric circuit is in general easier than the simulation of the real shaft and the result of the electric simulation can be used to describe the behavior of the shaft. Consequently, the control system for a mechanical part such as as shaft could be automatically simulated with an electric or electronic circuit through the use of a mapping table as part of product data definition.

More generally, in an integrated environment, The systems that are connected have different capabilities for handling a particular representation of the data. The use of an abstract description of the data which can have several concrete representations allows the choice of the representation that will result in the most effective data handling by a particular integrated system.

4.1.3.5. Formal problem decomposition

This approach provides a logical partitioning of the integration. The size of the PDES project implies that development of the integrated model has to be broken down into sub-tasks that can be carried out independently. The complexity of the relationships among different parts of product data makes its decomposition very difficult. The use of views and perspectives and the formal definition of different views and their relationships as the basis for decomposing the problem is a way of logically breaking down the complexity of the tasks. The consequent distribution and coordination of tasks would be built around this decomposition.

4.1.3.6. Acceleration of the development process through the surfacing of the assumptions reflected in the model

The concept of view, perspective and context allows the explicit and formal surfacing of different assumptions in the design. If these assumptions are not specified, the model will reflect the perception of the product by the modeler and the context in which a product familiar to the modeler is produced. Since product data include production data for PDES, a model will

reflect the process of manufacturing or design of a specific product in a particular context. For instance, if the modelers are working in the aeorospace industry, the model will reflect how a plane is made, and probably how a plane is made in a particular company but not how a car or a laundry machine is made. Consequently, if a formal way of surfacing the asumptions is not provided, the range of use and implementation of PDES and STEP will be substantially narrowed. While our approach does not provide a way to specify which representation should be used and what data should or should not be included, it has the advantages of raising early and systematically the problems that would have arisen sooner or later and of allowing a consensus on the solution for these issues in an early stage of the process.

4.1.3.7. Independence from technologies and applications

The concept of view and perspective is generic in the sense that it is independant from any technology and any application. This approach is especially relevant for PDES. Indeed, the implementation of PDES ultimately happens in a future totally integrated environment. The technology and even the distinction between mechanical and electrical application, for example, is constantly evolving and views that are at the present time irrelevant to an application may become relevant in the future. Product data modeling based on the generic concepts of view and perspective will accommodate this evolution. For instance, in the electrical domain, there is today little interest in finite element modeling. In the future, we may suppose that we have to design an electrical circuit board for a satellite. In this case, the vibration of the circuit would be an important problem. The "vibration view" sub-model of the product data model is independent of any specificapplication and thus can be used for this project.

4.1.3.8. Modularization and simplification of validation

Validation is simplified by decomposing it to validation within a view type and validation of the relations among view types within one perspective. Validation will be reviewed in more depth later in this chapter.

4.1.4. Hypothesis of the approach

In order for this approach to succeed, the following conditions have to be met:

- There is an agreement on different views , perspectives and contexts is reached among the various participants.

- The views and relationship among views are formalized through an information modeling language.

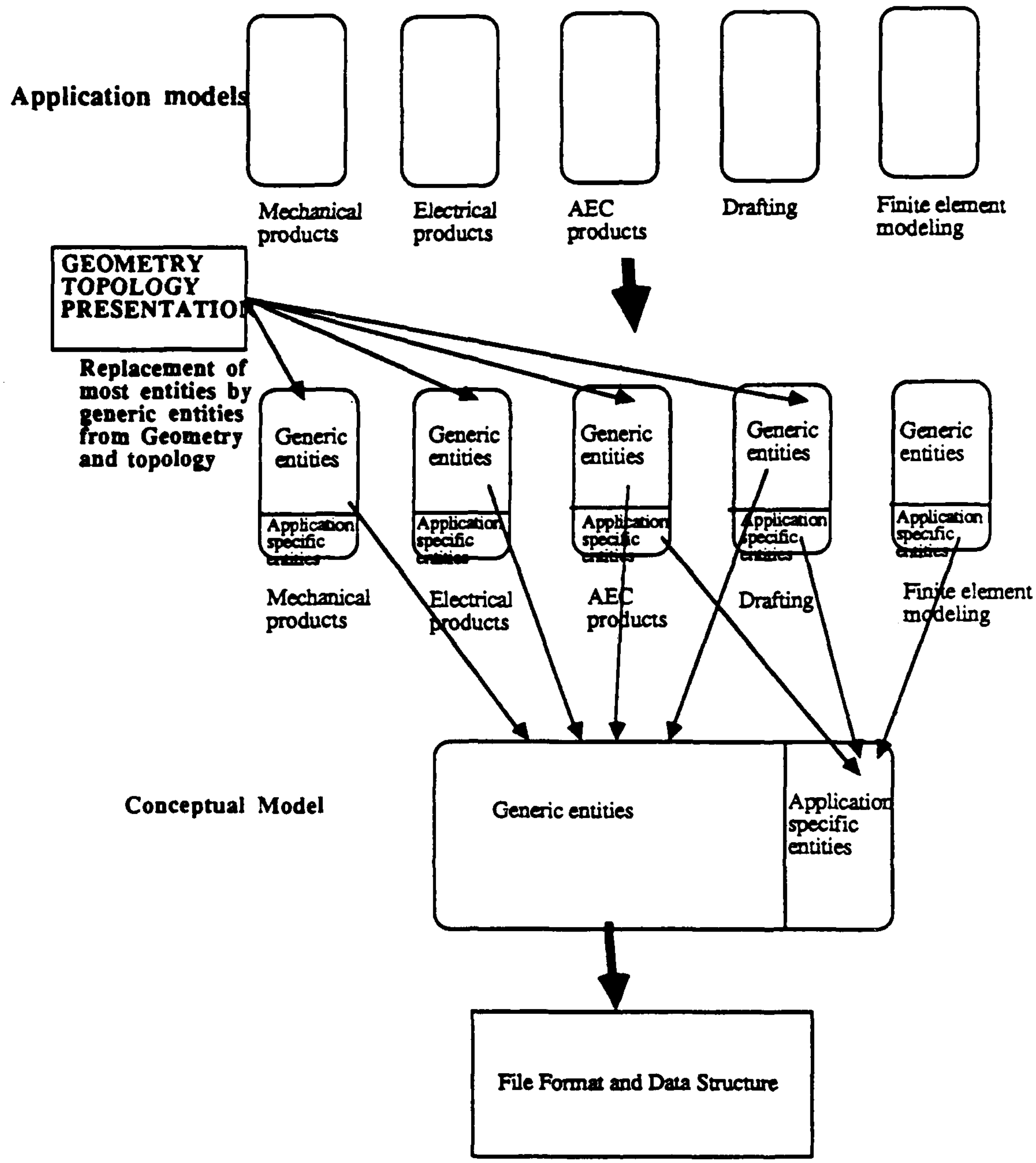
- The context and their relationships are formalized through an information modeling language.

4.1.5. The proposed architecture for PDES

The PDES project is organized in several committees corresponding to various applications at the application layer. As a consequence, each committee is modeling its discipline . The chairman of the mechanical application committee considers that " as application modelers, we should come out with a model of our application and we are not concerned with integration". He furthermore agrees that the model that will be generated will be more difficult to reconcile with other application models than if the organization has been based on views especially if the integration must be completed by few persons as it is the case at the present time.

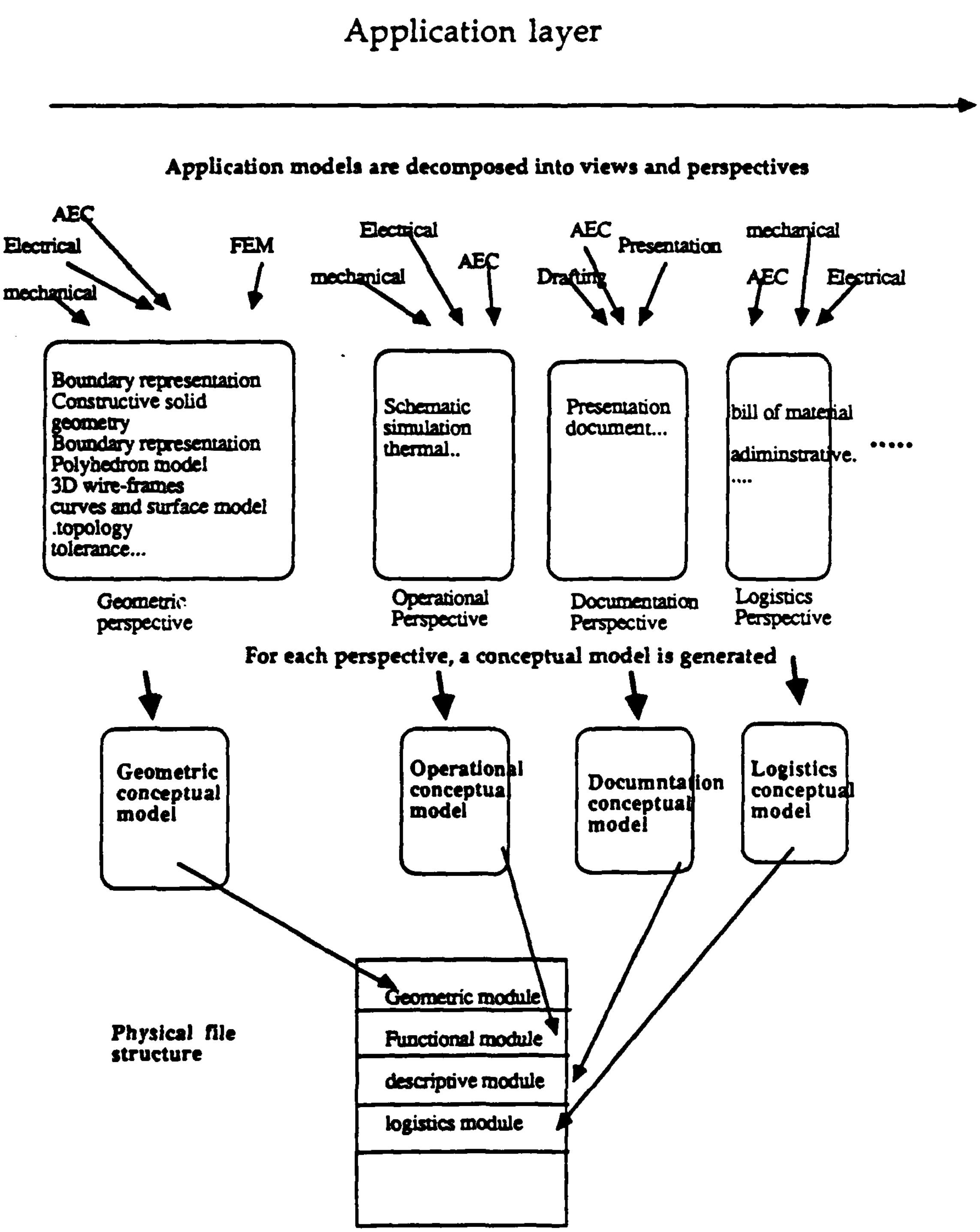
Fig. 4.11 and 4.12 shows the present and the proposed architecture with a preliminary idea of what could be some view types and perspectives. The real decomposition should occur after an agreement on the different views and a formal definition of the relationship among views.

A fundamental differenceamong the two approaches is that the proposed approach does not assume that all the applications entities could be defined by one conceptual schema but through a systematic way of defining views and of looking for the dependance or independence of views , the different views of object will be grouped in set of independent views corresponding to different schemas.



PDES PRESENT ARCHITECTURE

Fig. 4.11



<u>**Proposed Architecture For Integration**</u>

Fig. 4.12

After that the various views and perspectives have been defined, some members of different application committees for which a perspective is relevant should form a committee to generate a model from this perspective taking into account different contexts and their relationships. We consider that integration will thus be reached faster and in a more consistent way.

Table 3 compares some aspects of the present approach and the propposed approach.

Issues	Proposed Approach	PDES Present Approach
Principal assumption	A product data model can be decomposed into views and perspectives. Each perspective can be validated independantly. Generic entities are sought at the perspective level and no unique mental model is assumed	Most product data can be modelized using one set of generic entities and structures (a unique mental model). These entities would come from topology and geometry
Complexity	Pros: Formal and logical decomposition of the integration through views and perspectives Cons: introduce an extra layer of complexity in the architecture Fig. 4.16 (definition of views, perspectives and contexts)	Pros: separation between conceptual and physical level. Cons: did not provide a method for decomposing the integration.
Assumption Surfacing	Provide a formal method for surfacing of the assumptions in the model	Stated that assumptions should be made explicit but did not provide a method for doing it
Validation	Pros: Provides a method for modularization of consisitency checking.	Pros : Provides a method for external validity (walk-through). Cons: do not provide a mehtod for consitency checking.
Task Distribution	Provides a formal basis for organization and sub-division of tasks for the integration.	Integration is carried out by one committee

Comparison of some aspects of the Present PDES approach and the proposed approach for integration

TABLE 3

4.2. Project management assessment

4.2.1. Analysis of the organizational and project management problems

4.2.1.1. A problem of distribution and coordination of tasks among the PDES project members

At the present stage, the PDES project is more a technology development than a standard setting. Furthermore, this project is very complex because of its size and of the interrelationship of the different components of the project. Consequently, it is expected that the IGES organization acts like a team of researchers working together in the same place.

In reality, the different participants in the PDES project are coming from different companies, have different backgrounds and are scattered all over the world. Moreover, the number of meetings is limited to four per year and some of the meetings are joint ISO SC4/PDES meetings.

The number of meetings is limited by the direct cost of participation and the cost in terms of time. Indeed, expenditures such as travel, room and board expenses, and employee salary may be considerable especially when they are held across-continents. Furthermore, the different participants have full-time work besides participation in setting the standard , reading different material related to the standard, preparing and writing reports for each meeting. The time spent on these different activitie is a time that is not spent on their regular work and thus results in an opportunity cost .

During the recent meeting, a proposal was made to increase the number of meetings. This proposal was rejected on the basis of the dilution of the project through the diminution of attendance and the fact that companies will not send the same people to each meeting.

Consequently, the majority of the work cannot be done during the meetings and this work will have to be decentralized. The challenge is then : how to coordinate and distribute the tasks between the different participants so that that the time of the project is minimized ?

4.2.1.2. An important need for education and learning

A major factor that is contributing to the inability of the PDES project to meet its schedule is the lack of experience of the different participants with the approach and methodology used for PDES. This fact implies that most of the PDES effort was spent in acquiring the skills that are required for the project. Indeed,the people who have been initially involved in the IGES organization effort had in general no experience in information modeling and the modelers were not familiar with the PDES effort.

This issue has been very well expressed in the beginning of the initiation activities by the former chairman of the logical layer:

> "The first challenge for a standard group that historically has been concerned with product data exchange issues is simply to learn something about reference models and information modeling and about the requirement that any particular technique must satisfy in order to be useful. Another challenge is to effectively communicate the substance of these issues to people who are familiar with information modeling but are not familiar with product data exchange and to do this in a way that results in new talent being brought to bear on our problems."

As a consequence, the PDES effort have been first of all an educational and learning process where a substantial part of the effort was spent in learning the methodology. A quantitative example of this effort is the 1500 pages that were sent to the different members and that were supposed to be read in preparation of the April meeting.

A conclusion of the initiation activities report is the need for a better knowledge of the modeling techniques at the application layer and the logical layer. In particular, the project requires discipline liaison persons that are experts in their application areas as well as modeling experts. These experts must have a good knowledge of the modeling language used for the application as well as for the conceptual global model. Acquiring expertise in those areas was really time consuming, and important delays were experienced so that the people acquire these concepts.

I personally felt that the April meeting was an intensive university workshop. There was, on one hand, presentations of projects and tutorials where several participants were learning basic principles, adjusting their perception of the different issues and trying to map results of other participants experience to their problems. On the other hand, some application committees meetings required a high expertise in the subject.

An important part of the meetings was also spent in converging the approaches of the different members to the PDES project. For example, there is a lot of discussion about the meaning of integration. This specific subject came out through the entire April meeting and several hours were spent debating around different perspectives and conceptions of an integrated model. There was also a lot of discussions about the objective of PDES and its relation to IGES and the ANSI/SPARC methodology used.

An important challenge for PDES is then how to manage learning so that more time can be spent on the actual work. In the following, we present a framework for organization and a framework for learning that help us address these different issues.

4.2.2. A cooperative framework for the organization of the PDES project

In solving the organization problem of IGES, we have to address the following issues:

- *Task distribution:* who should perform the tasks and how should the information flow between different experts who have incomplete local knowledge?
- *Task coordination*:: should the decision for a resource allocation and information distribution be made locally or globally and how should the different decisions be coordinated among people who have local views of the problem?

We will use a cooperative problem solving framework to give some insights into the organization of PDES for the generation of the integrated model.

Classic theories of management see the process of management as a control process where a power dependency relationship is a determining factor in the development process. The solution of a management problem from this point of view is a compromise between conflicting goals and desires and competing forces [Cyert and March,1964 and Porter,1985]. However, in the case of the PDES standard development, we consider that the process is a cooperative one where people are experts in their field and have shared common goals and desires even if they have different approaches to the complex problem of designing a standard for product data exchange.

The main characteristics of this process are:

_ People are willing to cooperate that is they have a benevolent problem solving behavior.

_ The power dependency relationship is weak.

In order to coordinate and distribute the tasks, it is important to understand the different interactions between the participants in the development process. We will approach the interaction between the different designers of the standard through Davis and Smith [Davis and Smith, 1983] framework for cooperation in distributed problem solving. This framework is called "task sharing" framework. While this framework is directed to the field of artificial intelligence, we will map it directly to our context.

This framework supposes that the problem has already been decomposed and bases the distribution and coordination of the tasks on this decomposition. In our case, we have already accomplished a logical partitioning of the problem in views and perspectives.

This paradigm is a behavior model involving group members cooperating in the execution of individual design tasks. The designers are in this case a decentralized and loosely coupled collection of problem solvers.

Each designer is an expert in his field but has insufficient expertise to solve the whole problem and achieve the objective of the standard. Each expert spent most of his time working alone on various sub-tasks. He interacts with other experts only to present and exchange results(during the quarterly meetings in our case) or to request assistance on sub-tasks.

4.2.2.1. The task sharing framework

The key issue in the task sharing framework is how to distribute tasks among the different experts. Two aspects of the distribution are important in this framework: resource allocation and focus. The resources are to be shared between the experts so that the use of expertise of each member is maximized and that there is no overload on one of the experts. The focus implies that the task is allocated to the most appropriate expert.

The execution of a task is handled as a a contract which is negotiated between two experts. A contract begins when an expert encounters a task that is beyond his expertise or that is too large to handle. He requests assistance through a task announcement and is consequently considered as a manager of this task. The task announcement is usually local (limited broadcast or point to point broadcast) supposing that the manager has enough information about the specific capabilities of the other expert. Different local experts evaluates the task and answer the announcement if they are interested. The manager of the task evaluates the bids and awards the execution of the task to the most appropriate expert. This selected expert is responsible for its and is considered as a contractor for that task. A private report including a result description is used by the contractor to inform the manager on the state of the task until it has been accomplished.

The negotiation process is a recurring process. This task can be decomposed into sub-tasks and the contractor may further award contracts to other experts. We have thus a top-down elaboration of the contracts.

Characteristics of the task sharing

As we have seen, the coordination and distribution problem is solved through negotiation. The characteristics of this negotiation are:

- Its locality.
- Control is not centralized by a committee but it is distributed among the members
- the decision is made on the basis of mutual selection of the experts.

The process of evaluation and selection is local in the sense that each expert will base the decision on its own approach and that the decision will not go through a centralized body. Furthermore, the announcement is made locally and the expert have some knowledge about the potential contractors.

Mutual selection implies that both the expert and the respondents evaluate the offer from their own perspective.

Each task announcement carries an expiration time. If the task has not received any response, it may be reannounced later.

The different announcements should also carry a scale of importance so that the most urgent tasks can be assigned in priority.

The task distribution phase generates sub-solutions. we need to aggregate the sub-solutions. We base this aggregation on the 'result sharing" framework of cooperation [Smith and Davis, 1982].

4.2.2.2. The result sharing framework

In the result sharing framework, experts assists each other by locally sharing partial results. A solution is built through the incremental aggregation of sub-solutions. The partial solutions are based on partial information and are adjusted as more information becomes available. The solutions obtained by the different experts are insufficient and usually incorrect since they are based on incomplete knowledge. However, during the aggregation phase, the experts cooperate to eliminate errors and ambiguities. The correctness of the solution increases as more and more experts cooperate and the information available to these experts increases. This process would thus converge to an accurate solution from a computer perspective and to a "satisficing" solution from a human point of view.

4.2.2.3. Application of the cooperative framework to PDES

This framework is appropriate to PDES for several reasons:

- The hypotheses of the framework are in general met by the different participants in PDES. This point will be discussed in more depth later in the chapter.

- As we have seen, the limited number of meetings implies that most of the tasks are expected to be done by the experts alone. The general meetings are only for presentation, exchange of results and for reaching consensus on these results.

The framework addresses the task distribution and coordination by:

- Basing the decision for distribution of the tasks on local mutual selection.
- Decentralizing control.
- Sharing responsibilities among the participants.

In the first part of the chapter, we have provided a method for decomposing the problem of integration of the application models. we have specifically provided a partitioning of the model into views and perspectives. this partitioning is the basis for distribution of the various tasks.

In the case where a participant encounters a task where he has not enough expertise or that he can not handle by himself, he uses a local mutual selection to allocate this task to more appropriate experts. More specifically, based on his experience with the project and his knowledge of the different participants, he proposes the task to the participants that are the most appropriate from his point of view. These experts evaluate the task and respond to the offer. This " contract" is done locally. Consequently, the contractor does not need to formulate a request or obtain an approval from the planning committee. Furthermore, the contractor is fully responsible for the accomplishment of the task. For instance, during the April meeting, a *member of the electrical committee* announced that he had 'awarded' the task of modeling the physical aspect of an electric item to the former chairman of the logical layer committee and the latter informally replied that he had approved the award. This choice is an example of local mutual selection. It is based on a personal appraisal of the capacity of the respondent and this choice did not involve the planning committee. A general announcement of a task by a member of the planning committee should be avoided because the task allocation is not based on a previous knowledge of the experts by the contractor and thus will usually not lead to a good choice of an appropriate expert.

The distribution of tasks is independent of the structure of the organization. For instance, if a participant has been assigned as a task to generate a model of product data from a topology view, he belongs to the geometry committee until he finishes this task. Once he has finished the modeling, he can become member of any other committee if he has been awarded another task by this committee. thus, there is no fixed size of a committee or fixed role of any of its members.

The result sharing complements the task sharing in this approach, in the sense that some partial models will be regrouped locally. However, this process will occur locally only at a low level and would essentially occur within one set of views within a perspective. Sharing results across perspectives requires convergence of different ideas and should be done during the general meetings.

A typical example of result sharing would be a meeting between a contractor at a low level in the decomposition who has decomposed his sub-task into several sub-tasks and the several participants to which he has assigned the sub-tasks. The subcontractor will share the results among themselves and reach a consensus on the partial model. Some examples of local grouping in the case of PDES are the CAL- POLY Task team and the Peoria Project. The CAL-POLY task team works in cooperation with several other organizations for the generation of the electrical model. The 'Peoria' project aims to generate a mechanical model. In fact, these projects group an important number of members and there several subgroups for sharing partial results within each of the projects.

Task sharing will thus typically occur in some local meetings which are easier to establish and less costly. local result sharing is thus a process of increasing the speed of integration.

4.2.2.4. Benefits of the approach

- a very fast problem solving. The main advantage of task sharing is the high speed performance of the process. Task sharing has been applied to several problems of artificial intelligence and when the hypothesis that the framework presupposes are met, considerable improvement in the computational speed has resulted. in the case of PDES. As a consequence of the locality of the task distribution, the decentralization of the decision making and the use of local meeting for sharing the sub-results, we consider that the speed of integration will be substantially increased.

- An optimization of the use of the expertise of the participants. The distribution of sub-tasks as we have defined earlier allows dynamic

configuration of the different committees. The configuration of the committees is thus based on the expertise of the different members and not on an a-priori configuration as it is usually the case and there is no fixed size of the committee or fixed role of a member of the committee. This structure optimizes the use of the expertise of the different members participating in the standardization process.

Furthermore, the task sharing framework forces more exchange of information between the participants on the appropriateness of the assignment choice of a task to a participant. Moreover, a personal choice reduces the probability of interpersonal conflict or misunderstanding .

- In a standardization process. the participants in a standard are constantly changing. The fact that the responsibility is shared among different experts reduces the impact of a resignation or decrease in the level of activities of one expert.

- The standardization process is based on a voluntary participation. The task sharing framework corresponds to this fact since there is no constraint by the organization leaders on the choice or the decision of the different experts to accept a task

- The decentralized approach makes the problem problem conceptually much simpler for the expert who has to focus only on its specific part of the problem and there is an important reduction in the flow of information that has to be exchanged.

4.2.2.5. Shortcomings of the approach

The result sharing framework assumes that during the gathering of the results, an agreement between different experts will be reached in a reasonable time. However, since each sub-solution is generated independently and based on the independent evaluation of the experts, if the results are not shared frequently we may obtain an important divergence in the views and this factor will slow the process.

-We presented a scenario where the actors in the standard development are a loosely coupled collection of problem solvers who solve the problems

through negotiation. However, the framework we presented do not tell us anything about the evolution of the expertise of the different participants during the the process. In fact, most of the expertise is acquired by the designers during the development process and we need to consider the effects of learning on the negotiation process and the development process in general.

4.2.3. The Learning Framework

In the cooperative framework we presented, we considered that the PDES development process is a problem solving process.

Kolb (1974) argues that the characteristics of problem solving and the characteristics of learning should be combined and that the problem solving process is a learning process.

Kolb considers that problems are usually specific rather than general, concrete rather than abstract and that problem solving is linked to the life of the problem solver and that in fact, it is the involvement of the problem solver in the problem that makes it a problem.

A problem solver generates from his experience concepts,rules and principles to guide his behavior in new situations and then modifies these concepts as a result of his observation of new experience in order to improve their effectiveness. This process is both active and passive, concrete and abstract.

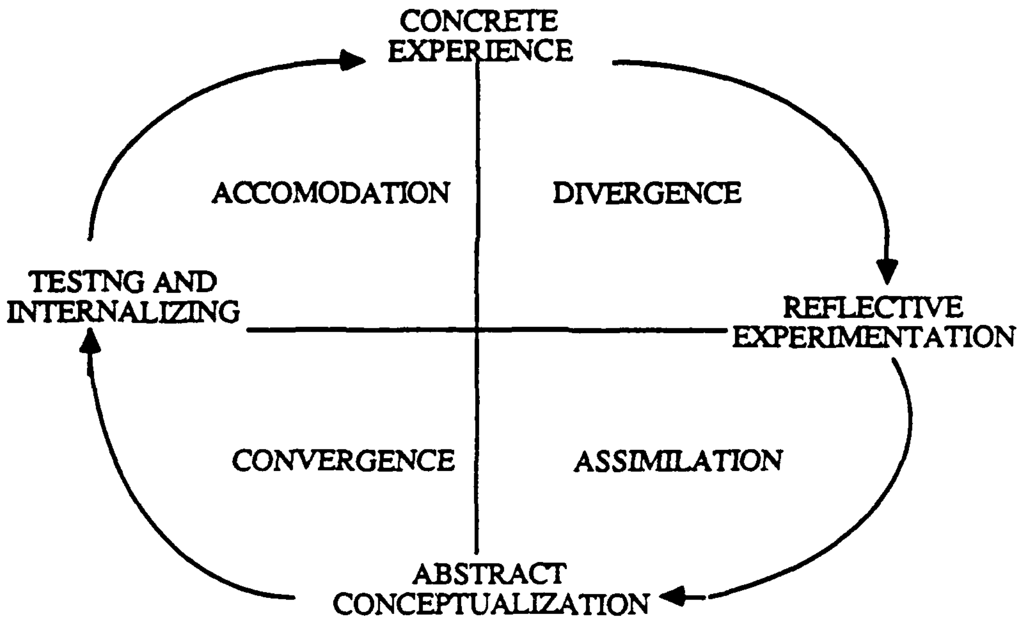
Learning in this model is conceived as a four stage cycle (Fig. 4.13). In the first stage,there is an involvement in new , concrete experiences. These experiences are the basis of observation and reflection. In the third stage, there is a creation of concepts that integrate these observation into theories from which new implication for actions can be deduced. The fourth stage is thus for testing and internalizing.

A good learner must be able to:

- Involve himself in experience openly and without bias in new experiences (concrete experience).

- Reflect on and observe these experiences from many perspectives (reflective observation).

- Create concepts that integrate his observations into logically sound theories (abstract conceptualization).



<u>THE EXPERIENTIAL LEARNING MODEL</u> (Kolb 1970)

Fig 4.13

- Use these theories to make decisions and solve problems. (Active experimentation).

There are several implications of the learning model:

- Learning is a cyclical and continuous process and consequently all learning is relearning and all education is reeducation

- Learning is related to the learner's goal. The interpretation of the experience is in the light of the learner's goal. The concept formed and their testing is based on the learner's needs and goal. Consequently, learning will be inefficient if the goals and objectives are not clear.

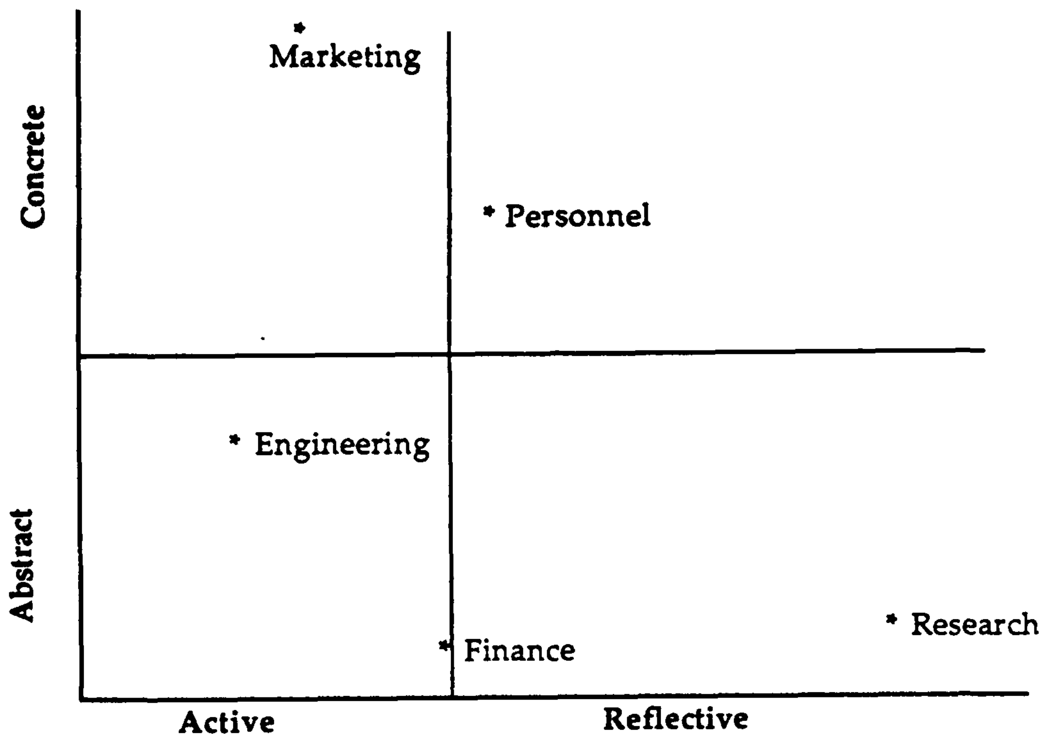
- Learning depends on the individual styles and a person who has been involved with practical experience in the industry will have a concrete and active learning style while a modeler from the university may place greater emphasis on abstract concept.

- the four learning abilities we have described correspond to four different learning styles respectively accommodation, divergence, convergence, assimilation.

The Converger's dominant learning abilities are abstract conceptualization and active experimentation. His greatest strength lies in the practical application of abilities. The Diverger has the opposite learning strengths of the Converger, he is best at concrete experience and reflective observation. His greatest strength lies in his imaginative abilities.

The Assimilator's abilities are abstract conceptualization and reflective observation. His strength lies in his ability to create theoretical models,excels in inductive reasoning and assimilating disparate observations into an integrated explanations. The Accomodator on the contrary is best at concrete experience and active experimentation. He excels in the situations where he must adapt himself to specific immediate circumstances.

Fig. 4.14 shows a classification of the learning styles by function in the organization.



<u>Categorization Of The Organizational Function By Learning Style</u> (Kolb 1973)

<u>Fig 4.14</u>

4.2.3.1. Application of the experiential learning model to PDES

As a technology development project attempting to generate a complete product data conceptual schema and oriented toward a future environment, there is no concrete experience coming from an implementation of PDES. Consequently the reflections of the different members will be based on their own personal experience and the experience they had with IGES , PDDI or other projects. The learning in this case will not be an experiential learning but more a learning by analogy. Since PDES concept is quite different from the concept of other projects, the analogy is far from perfect and the observations and reflections will differ drastically depending on the project or experience on which their experience is based. There is consequently a lot of education that is needed to accommodate and orient these reflections.

An important number of participants are coming from an industrial environment and are managers of some project in their company. Consequently, their style is an accommodation style that is they are best at concrete experience and active experimentation. Thus,they will tend to think at the physical level and make the project bottom driven.

At the present stage, the PDES project needs people with an assimilation learning abilities to generate conceptual model and at the same time have enough experience with the manufacturing process. The results that are shown in Fig. 4.14 implies that PDES needs more research oriented people style. Since most of the participants learning styles do not correspond to this style, the learning process is likely to be slow for the majority of the participants.

- The model implies that the fact that the concepts of PDES are not clear explains the inefficiency in the learning. The lengthy discussions about the meaning of integration and so on are attempts by each participant to define his goals and needs and unless these goals and needs are made clearer, the learning process is likely to remain slow.

4.2.3.2. Presentation of methods for speeding learning

4.2.3.2.1. Prototyping

Prototyping consists in simulating the whole development process and going through the whole learning cycle in a limited amount of time and using limited resource. Basically it is a design on a reduced scale and with a limited scope. It emphasizes the evaluation of performance

There are several advantages in prototyping :

prototyping as a technique for requirement definition.

The usual design methodologies impose the creation of a well defined,well structured tasks and a detailed action plan. However, in our case ,PDES presents a new methodology and a new approach to standards. Consequently, the different tasks are poorly defined at the beginning of the process. Furthermore ,as an innovation process, the process itself is expected to be highly variable. A prototype is expected to generate an important interaction and negotiation in a short time. Based on the distributed problem solving paradigm, this negotiation will generate different tasks and sub-tasks and give a first idea about the expertise needed during the process and the distribution of these tasks.

Prototyping as a source of learning

During the prototyping phase , the developers go through the major phases of learning cycle, the important interaction between the different designers usually results in an important learning.. It is also an important way to involvement in new and concrete experiences and thus constitute an the first step in the learning life cycle.

Prototyping as a validation technique

The initiation activities report states that these activities aimed to validate the concepts and the proposed methodologies. From this point of view, it is a proof of concept that demonstrates the possibility of the project.

4.2.3.2.2. Reaching consensus on the critical assumptions of the problem

As a loosely coupled collection of problem solvers the people involved in PDES has different approaches to the problem. In the first part of the chapter, we defined a method that allow the surfacing of different assumptions in the models. We need also to surface the assumptions on how the different participants see the objectives of PDES, different concepts in PDES, and the management of the PDES project. The surfacing of these assumptions would lead to the alignment of the various approaches of the participants and thus a reduction in the time spent in discusions about this subject.

Several research in the IS field argue that core beliefs will establish how interpretations are made and that consistency of beliefs among designers influence the performance in the design. Henderson and Sifonis argue that the likelihood of a successful design can be increased by attempting to reach consensus on critical assumptions. Richard Mason and Ian Mitroff designed a method for surfacing assumptions called SAST (Strategic Assumptions Surfacing and Testing Methodology). Mason argues that complex problems are those that require the interaction and sharing of information and perspectives from different disciplines which is particularly our case. Each person has his own biases and "Tunnel Vision" when formulating the problem and working through it. If these assumptions are not mentioned, this would result in an inappropriate definition or conceptualization of the problem besides the conflicts that will arise.

In this method , working groups are formed. These groups develop different perspectives with regard to the set of issues under discussion. They then surface the set of critical assumptions that underlie their view of the problem through oriented discussions. The outcome of these discussions is a consensus on a set of important assumptions. The different participants identify among these assumptions, the ones of high importance and uncertainty (pivotal assumptions). the final outcome is a formulation of a plan for monitoring the pivotal assumptions over time.

4.2.3.3. Implications of the experiental learning model for PDES

The importance of the learning and education in PDES implies that the managers of the project should explicitly manage the learning process. In particular

- Learning should be an explicit objective of PDES pursued as consciously and deliberately as the development of the standard. We recommend more specifically that the documentation of each committee contains concrete examples of what they are trying to represent in their model. <u>The thousands of pages describing the different models do not contain till now any simple and specific example explaining what the models are trying to communicate.</u> A separate English description of each entity is not enough. It has to be complemented by a concrete examples of the reality showing how the model works. These examples should explain step by step and in English how the model is constructed. The electrical committee is the only committee who tried to accomplish a similar objective by representing a specific example of their model, however the explanations were not explicit enough so that each person could understand the model. Furthermore, documents like the initiation activities report containing comments and feedback should be systematically made at each step in the PDES process.

- in order to accommodate the different learning styles and explicit the objectives and assumptions, some sessions should be reserved for presentation of concrete examples of the models During the meetings.

<u>4.2.3.4. Hypothesis of the framework</u>

- a. The organization is a set of problem solvers.

- b. Every participant in the problem solving process is an expert and has a benevolent problem solving behavior.

- c. All participants are willing to cooperate even if they have different approaches and views of the problem.

- d. The power dependency relationship is weak and political conflict will not be predominant.

- e. Every expert has an incomplete knowledge of the whole problem but he has a good knowledge of his area of expertise and understands how his subproblem affects or is affected by other subproblems.

- f. The problem is decomposable into sub-tasks that are affected by or effect only few others subproblems. so that a local negotiation and local task announcement - bid - award is sufficient.to solve the subproblem.

- g. Learning is an important aspect of the process

4.2.3.5. Justification and discussion of the hypothesis

Justification of the cooperative aspect of the process

A standardization process offers usually both a market, political and technical aspect. The market aspect do not play an important role till the present stage. The following reasons explain such an unimportant role :

- the PDES concept and objective are still evolving and not very clear for the outside world as well as for many people inside the IGES organization. For example, very few people which are not involved in the PDES development know the difference between IGES and PDES.
- there is no implementation or testing at this point of PDES and the development is still a design and innovation work at a theoretical level.
- few sellers participating in the meeting is low and the majority of the participants are technicians.

There is a certain political aspect in the PDES development which is due to the fact that PDES is a real research and technology development on conceptual schemas and formal perspectives. As a result, it would be a good field for demonstrating the validity of an information modeling language or an information system design methodology. Furthermore, the adoption of a methodology by an such an international body may lead to the adoption and even the standardization of such a methodology. This offers an explanation for the "competition " between NIAM , IDEF1X and to some extent EXPRESS.

Despite this fact, the technical aspect is predominant in the PDES development process and most of the issues raised during the meeting have a strong technical orientation. These factors explains to some extent the cooperative behavior of the participants. The different participants are aware of the important technical difficulties that they are facing and are very interested in solving such issues (the meetings go from 8 A.M to 11 P.M). The atmosphere during the PDES meetings has been described by more than twenty participants that I asked on this specific aspect as a true cooperative atmosphere. Despite the fact that the last meeting is a joint PDES/ISO meeting where the international participants are supposed to represent the position of

their countries, their behavior is more technician and researcher than a political behavior.

Cooperative behavior is a determinant aspect of the process of standardization not only at the designer level but also at the standard setting organization level. In this case, there is a close cooperation between the NBS, ANSI, IEEE and ISO. The importance of cooperative behavior is reflected in Marvin Sirbu study of the communication standard X.25 [Sirbu,1985]. Sirbu finds that standards of higher quality and greater generality are likely to be produced if standard setting organizations cooperate with each other during the development and drafting of new standards.

The predominance of the technical aspect over the other aspects in PDES standardization process is in discord with the findings of the literature in the field of computer and communication standards. The standardization process is analyzed from a market perspective. From this perspective,the different participants in the standard are manufacturers and buyers of the product that will act on their own self interest. The decision is based on an attempt to minimize their costs and maximize their benefits. The process of standardization is thus a conflict resolution standard.

[Sirbu,1985] finds that the political aspect is predominant over the technical aspect in the negotiation for the setting of the LAN standard and considers the standardization process is a three phase process:

- The first phase is a slow start where people learn how to work together.
- The second phase consists of heavy debates and battles where positions and differing fractions are formed. The members of each group have their own view of the standard and the approach to the standard. People with different perspectives coalesce into like groups when they find other with ideas that resemble theirs.A compromise is reached at the end.
- In the third phase, the committee builds consensus and begins to ratify the standard. Representative from small firms begin attending trying to get their specific applications considered for the standard.

We consider that Sirbu addresses an advanced phase of the standardization process where some implementation of the standard has already occurred. The present stage of PDES is still a technological development of the standard.

analysis of the importance of learning and education

The chairman of the logical layer committee remarked that during the December 1986 meeting the discipline models that have been accepted and agreed upon are models on which work have been done for five years through other projects like PDDI. This example stresses the importance of experience and learning in the process.

EXPRESS is an interesting example of the use of the standardization process as a learning process. EXPRESS is originally a data specification language that has been developed through the development of the PDES project. There have been several versions of EXPRESS sent to the different participants in the PDES project usually before the general meetings. Some participants even complained about the important amount of time that they spend learning the different versions of the language. Since the models are to be ultimately translated into EXPRESS, the feedbacks from the different modelers and the interaction of the logical layer committee with the application models resulted in successive additions and improvement to the language. EXPRESS is now both a Conceptual Schema Language and a Data Specification Language through its abstract and concrete schema and some application committees are directly translating their models into this language and it is likely to be the language for the integrated conceptual model.

The literature stresses the importance of learning and education. Sirbu and Hughes (1986) studied the standardization of the local area network and conclude that:

"standardization activities are increasingly being undertaken as a mean of clarifying new areas of new technology which are poorly understood, both technically and from a marketing perspective. No analysis of standards which assumes that all parties have an equal comprehension of the subject matter and differ only in their economic interest can adequately explain the behavior of the participants. As standards become more frequently developed in advance of well defined market demand, the process come to resemble the act of innovation in which firms try to develop new technologies to satisfy

unclear needs. firms frequently misapprehend either the technology or the market or both. The complexity of the issue being addressed means that much of the effort in the development of standard lies in the process of educating the participants to a common perception of the problem to be resolved."

Expertise and limited knowledge of the participants

The different participants are engineers,technicians and project managers that have a good experience and high expertise in their domain. Several people have an extended expertise in information modeling. However, as we have already pointed out in the begining of this chapter, the PDES project requires both a good and wide knowledge of information modeling technology and an extensive experience with the industrial and manufacturing field. Furthermore, the project is of a very important size and complexity. All these factors imply that each expert has an incomplete knowledge of the problem and that the problem has to be decomposed into independant tasks.

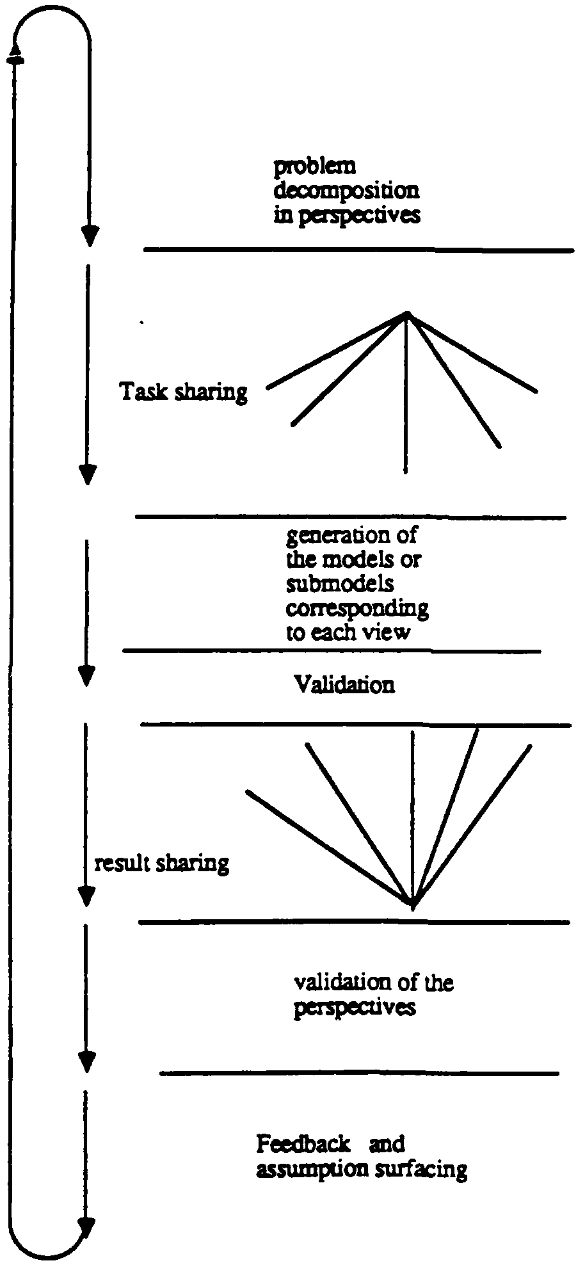
4.2.4. The cooperative and learning framework proposed for PDES

The importance of learning in the PDES process implies that there should be several iterations of the whole problem solving process resulting in several drafts of the standard. The initiation activities phase was from this perspective a good attempt to define more precisely the problem and receive more feedback. However, it is an incomplete experience since no implementation occurred and no concrete experience was thus generated.

The method we propose is based on an iteration of the task sharing framework with a management of learning :

- Problem definition and decomposition where the views and perspectives are generated
- Task distribution where the tasks are distributed among the modelers using the task sharing framework.
- sharing of the different results in the local and genral meetings.
- validation of the result of each step.

Fig. 4.16 shows an example of such a process.



Example of the process of integration

Fig 4.15

4.2.5. Comparison of the different proposed methodologies with the litterature on innovation

When describing PDES objectives, we have articulated the fact that at the present stage, the project is more a research and development project than a setting of standard. The nature of the problems presented here demonstrate that it is actually the case and from this point of view,the effectiveness of the proposed strucuture is consistent with the results of the literature which link organizational strucure and performance or productivity in R&D an innovation projects.

Allen(1986) argues that there are conflicting goals in structuring R&D organiztions. On one hand, organization by disciplines and technical specialities provides a strong connection to the knowledge base underlying the organization's work. However, the output in R&D organizations do not take the form of discipline or technical specialities but is in general in form of products or processes that require simultaneous application and coordination of disciplines or technical specialities. The specialized functional group presents a barrier to coordination an can become difficult to manage. The response to this problem is by bringing all the engineers together in the same organizational and physical location. However, in such an organization, the engineers are in the long term isolated from their supporting technologies. A good solution is to use combine both structures. The organization by perspectives provides this mix since it allows a functional structure where people from differnt disciplines cooperate together.

In such a structure, the task sharing framework provides a shared and balanced responsibility between the project managers (in our case,the responsibles for a committee corresponding to a perspective) and functional managers (the different contracors). However, this shared responsibility is perceived only internally and from an external point of view, the responsibility is centered on the project manager since contracts are local and private. The efffectiveness of such an organization is also consistent with the findings of Katz and Allen (1981) who examined the relationship between project performance and relative influence of project and functional managers in an R&D and innovation settings and showed that performance is highest when the internal influence is perceived as balanced between

project and functional managers but when external organizational influence is considered centered in the project manager.

4.3. Validation

Several members of various committees of the PDES project have expressed the lack of mechanisms for validation in PDES. Specifying a methodology for validation is beyond the aim of this thesis. However, we would like to define more precisely the notion of validation,stress its importance and expose some ideas on how validation could be conducted within the approaches for problem decomposition and the learning framework that we have defined earlier.

4.3.1. Definitions

The purpose of a design is the creation of validated specifications of the model within the context of the design. In other words, the essence of any design is to obtain an output so that the degree of match between this output as it is and the theoritical requirement (the output as it should be) is maximum. When this degree is high, we will say that the model is correct.

Lundberg(1983) defines three criteria that an information or conceptual model has to verify in order to be correct: consistency, satisfiability in the universe of discourse and completeness.

Consistency : a theory is said to be consistent in a universe of discourse if we can not deduce a sentence and its opposite from the set of axioms forming the theory by the application of the inference rules of the theory. Consequently, consistency is a measure of the degree in which a design is expressed in logically related descriptions and representations.

From the definition, it follows that an information model is true in some universe of discourse which may not be the one that the modeler wants to consider. This fact stresses the importance of the context in which a model is validated.

In practice, it is very difficult to show the consistency of the model. In fact, existing methods for checking consistency such as the application of the resolution principle (Chang 1973) only demonstrate that a model is not inconsistent.

Satisfiability: a model is satisfiable if we can find a universe of discourse where the information model is true or totally consistent and this fact holds

only in that universe of discourse. In other terms, it is the "largest" universe of discourse where a theory is consistent. Satisfiability is thus a measure of the preciseness of the model.

Lindberg shows that the checking of this criteria assumes the availability of an information base containing all the facts related to the universe of discourse considered. This set of facts is also referred as the concrete knowledge.

Satisfiability must be checked by an information model with a representation of all possible concrete knowledge. In practice and in the case of PDES, in order to check the satisfiability of a product model, we need to have information about all the products that are manufactured.

Completeness: a consistent theory is said to be complete if all true sentences are deducible from or represented in the information model. In practice, all theories are incomplete except for very simple models.

These definitions stress the difficulty of validation of the reference and the integrated model. In practice, there are few technical tools available for checking the *internal consistency* and the degree of consistency of the model is based on the coordination and coherence between the different tasks in the design process. The complexity of the task facing the different members of the IGES organization implies that consistency checking is a task that cannot be done by a member or a committee but has to be embedded in each step of the design process and has to be modularized.

In the following, we present some ideas on how consistency checking could be performed within the "view" approach.

4.3. Validation within the 'view' approach.

The validation of a model at the logical layer is defined through the properties that it has to fulfill in order to be used properly by the physical layer. Some of these properties are:

- The model is detailed enough for the generation of the standard.
- Each instance of this model will behave as required in the model

- The form of expression of the model is legible enough so that the access to the lexical items defining the views of the model is unambiguous.
- Various part of the model semantically represent the same thing.

The first three properties are required for the checking of the satisfiability and completeness of the model, that is, they allow an easy and consistent checking of the concaptual model (the abstract knowledge) with the concrete knowledge. The last property is the result of a consistent model.

In the proposed approach for integration, validation is an integral part of the design process. The design process is partitioned into design steps recursively and sequentially chained. Each step has to generate a valid result before the next step can begin. The integration plan for PDES defined in april 1987 (figs 3.3 and 3.4) is a good example of a process where validation exists at each stage of the integration process. Indeed, at each step, there is a review by external people of the model and a case testing and queries that are run on the model.

Furthermore, at each step, the product data model has been decomposed in a set of perspectives. Each perspective is a tightly coupled group of views. At this level,we need to check:

- the coherence and consistency among different views within one perspective and the consistency among perspectives. This implies that each refinement, correction, addition or update in the product specification is reflected through parallel changes in different views.
- the validation of the different views and perspectives against the applicable context. As we have seen, a context is the reflection of the environment of the product and thus each context imposes certain constraints on the product. Consequently, the definition of the relevant universe of discourse is related to the context of a product. Since an information model is satisfiable for a specific universe of discourse, a product data model is valid for a specific context.

In the following, we give some directions for consistency checking within the 'view' approach.

4.3.2.1. Consistency

We have decomposed the product data model into views and perspectives; each perspective can be validated independantly of other perspectives. Furthermore, we have introduced the concept of version in order to isolate the different changes in the design and the concept of delta-view to capture the modification of the design between two view versions.

The decomposition in views and perspectives implies a modularization of the consistency checking. Indeed, as a set of views, checking the consistency of a perspective is accomplished by checking the self consistency of a view and the consistency of a view with other views.

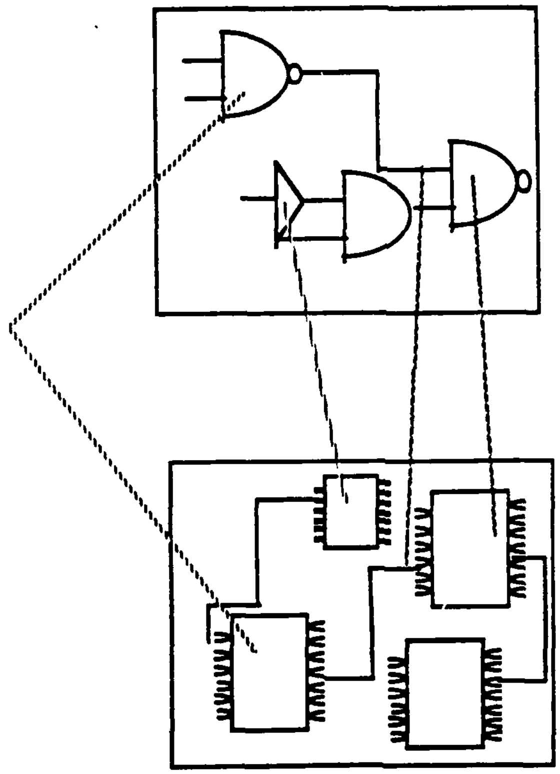
Thus there are fundamentally two kind of consistency checking:

- *self consistency* is the comparison of an instance with its type. More specifically, it is checking if a view version is a valid instance of view in the scope of its context version.

- *cross consistency* is the comparison of two instances of a view. More specifically, it is the checking of the fact that a set of view versions belonging to the same object version are not conflicting instances of views. This kind of checking arises because two views overlap. for example, a bill of matrial is derived from the break down of a product into its components. Consequently, a bill of material view is closely linked to an assembly view and a change in an assembly view version must be reflected in the bill of material view version of the same product version. The relation between serialization and deserialization (data communication representation and data storage representation also results in a cross view type dependance between the two view versions associated with each type.

Fig. 4.16 gives a simple example of the checking of cross consistency. In this case, we have to check that each part and each connection in the schematic view has a correspondant in an assembly view.

While this approach simplifies the checking for each subpart of the model, the complexity of the consistency checking remains at the level of the cross consistency. Cross consistency may become very complex if we consider that we have not only to check consistency between two views but also between two set of views. However, the introduction of the notion version



Consistency checking between a schematic and assembly view of a printed circuit board

Fig 4.16

and delta-view simplifies the consistency checking. Indeed, once the consistency checking is done for a version, we can check the consistency of another version by only considering the change from one version to another using delta view.

For the PDES project, several application models are ready. these models are composed of several views and are already reflecting the dependency relationship between different views. Consequently, we recommend that these relations are explicitly formalized using a language such as EXPRESS during the processus of separation of the views for integration. In this manner, the cross consistency checking will be easier to capture when changes in the model occur. Furthermore, there should be a systematic checking that is associated with each new version so that consistency among different data models is maintained.

4.3.3. Validation within a learning approach

The learning cycle that we presented stresses the fact that testing is a phase in the learning cycle where the theory is compared to the practice. The feedback that is received from previous testing derives changes in the concepts which require new testing. with the accumulation of experience, the learning cycle is stabilized and standardized procedures are generated for validation and testing.

Consequently, mechanization and automation of validation needs an important amount and learning and education from the designers.

This approach is more oriented toward validation at the physical level that is insuring that the standard to implement will function properly and that the standard is thus of a good quality.

Several techniques are used for that:

-*Sampling:* the quality of the standard is checked through the testing of of the behaviour of the standard in a random or formally defined set of instances.

- A-priori qualification: the data available from the design process are used to predict the quality of the model.

- A-posteriori qualification: prediction of the quality of the standard from the analysis of the model.

For its simplicity,the most widely used method is sampling. However, it is also poorer than the other methods as far as accuracy is concerned.

The learning model implies that a-priori qualification is very difficult especially in the case of PDES where not enough experience has been generated. It explains the important difficulties that the testing and implementation committee had in generating recommendation for validation of the standard since no sampling occured yet and they are enable to do a prediction of the quality of the standard from the analysis of the model because this committee is independant from the logical layer committee and consequently has a poor grasp of the model.

4.3.4. General recommendations for validation

We recommend that the prediction of the quality of the model and the checking of the consistency be an integral part of the modeling. Each committee that generates a model should check the consistency and the satifiability of the model. within the framework proposed, it would thus be done at the level of each perspective. More specifically:

- The process for integration as defined in the April 1987 meeting include consistency checking through data modeling and testing tools, test cases and queries and satisfiabilty checking at every step in the process. Such a process should be applied but at the view and not the application level(see Fig.3.3).

the result sharing involves the presentation and integration of partial models representing views. During these sessions, the relations between different views that have been formalized as we have presented earlier should be checked. The presentation of the partial models to the other participants should focus on the checking of the consistency within a view.

Furthermore, the use of model walk-throughs where a partial model is presented to several industrials and technicians from different backgrounds and is thoroughly discussed is very useful in the sense that it provides an important feedback and learning to the modelers and is a very good way of verifying the satisfiability and even the consistency of the model. Indeed, during this meetings, the participants will typically map this model to some

products that they are familiar with and see if the model responds to their product which is a confrontation of the model with the concrete knowledge. However, these participants should be aware that the model reflects a particular point of view in a particular context and in general the model should be well explained before any evaluation starts. An efficient way for doing this is writing a document representing an english description illustrated with several examples as precise as possible of the model. This documentation would be sent in advance which will reduce the meeting time and thus increase the participation to these meetings. This documentation will actually be also very useful for the other PDES members. The document will be very helpful for achieving the maximum of completeness of the model since it can be sent to other industrials who could not participate in tthe walkthrough meetings.

4.4. Summary

We have defined a formal method which provides a decomposition of the problem of generation of an integrated model for PDES and a basis for organizing and distributing tasks among the different participants. This organization is output-foccussed, that is, it decomposes the deign of the integrated model into logically and loosely coupled parts and that this decompositionis oriented toward the generation of an integrated model and is independant from the different applications and technologies. Furthermore, this method allows a formal surfacing of different assumptions in the design and thus reduces ambiguity and inconsistency in the model and accelerates the process of reaching consensus on a neutral data representation. Furthermore, it allows a better data configuration management and a formal partitioning of internal consistency checking.

we then presented a cooperative framework for task distribution and coordination where the different participants in the development process are considered as a loosely coupled experts and problem solvers. The distribution of task is based on local mutual selection and the execution of a task is handled as a a contract between two experts. The reponsibility for different tasks is decentralized and distributed among the participants along with the allocation of tasks. The different partial results are then shared locally at a lower level and globally at a higher level.

We have considered the standardization process as a learning process. We presented an experiential learning model where learning is conceived as four stage cyclical process and depends on the personal learning style. The learning and education of different experts is managed through the use of prototyping and the generation of a clear and concrete documentation and feedback at each step and iteration of the process.

The validation of the standard is considered as an integral part of the standardization. Internal consistency checking has been simplified by using the decomposition into views and perspectives. The checking of the

satisfiability and the completeness of the model is accomplished through the presentation fof the model or review by the industry at several stages in the process.

5. Recommendations and conclusion

5.1. Recommendations for the PDES project

We approach the development of the PDES standard as a design activity and the PDES development process as a problem solving process. From this point of view, the fundamental issues that has to be addressed are: problem definition, problem decomposition, task distribution and coordination and validation. We present in the following some recommendations for the generation of the integrated model.

Problem definition and decomposition

This set of recommendations is completely consistent with the recommendations presented by the chairman of the electrical committee for facilitating the process of integration. It aims to organize the modeling by data scope with participants from multiple disciplines.

We recommend the use of the view type approach and the concept of modeling technology for the generation of the integrated model. Furthermore, to reach the latter goal we suggest the steps outlined in the following paragraph:

1- Organize a workshop where the concepts of view, instance and versions as applied to views and products, and contexts are presented and discussed. These different concepts should be refined and formalized as much as possible. The output of this workshop would serve as the first agreement of the different views and contexts that are relevant in the PDES context and the boundaries between different views. The participation of some people from the ISO/SC5 committee who have some experience with a similar approach would be helpful.

During my discussion with the different participants for the last PDES meeting, I found that most people agree that they should explicitly define how they are viewing the models. In fact, there were several inter-disciplinary meetings around this notion. What is needed is to formalize the latter process.

2- Decompose the different application models and the model that has been generated by the logical layer committee by views. This process should also generate an understanding and even a formalization of the relations between different views. Systematically identifying the links will be very useful for checking the consistency between views. Some new entities may need to be added in order to formalize these links.

3- Provide a first organization of the views by perspectives. The output of this phase would be a systematic way of defining, organizing the views and the relations between the views. This step needs a careful study and consensus since the subsequent structure for integrating the different application models should be based on this concept.

4- Define different relevant contexts and their relationships. This step is important since the validation of a model depends on its context. EXPRESS may be used for formal definition.

5- *Define the views, perspectives* and contexts as rigorously as possible using a formal modeling language such as EXPRESS.

6- Analyze the use of a formal language like EXPRESS for checking the view versions.

<u>Task distribution and control</u>

7- Organize the integration around the concept of perspective after an agreement about the definition of the different relevant perspectives has been reached. We suggest the establishment of committees corresponding to each perspective. The different tasks should be carried out locally by each committee possibly using projects such a the Cal- Poly task. The distribution of the different sub-tasks would be based on the suggested task sharing framework. In particular, the control should be decentralized and shared among different participants as defined in the framework and the different participants could belong to several committees and switch from a committee to another depending on the tasks they handle.

8- Share the results within each committee corresponding to each perspective locally using local meetings and projects like the Cal-Poly project. The different results of each committee should be shared in the general PDES or ISO meetings.

9- Each committee should generate a clear documentation with concrete illustrations and examples explaining step by step how the model fits the products. This documentation should be addressed not only to the different members of the IGES organizations but also to the industrial community for external validation and consensus. At the end of each phase of integration, generate documents summarizing the work and presenting different feedback of each committee.

10- Once a version of the integrated model has been generated reiterate the process until the model converges.

Validation

We did not address this issue in depth. However, we recommend that the procedure for validation presented by Gale Roger in the April 1987 meeting should be applied. More specifically, checking the external validity of the model through " walk-through meetings" and the internal correctness of the model within committees during the result sharing process and between committees during general meetings should be applied.

5.2. Conclusion

The development of standards has been and is still considered as an ad-hoc process where interested parties struggle to get their standard accepted. We have shown that for standards for an integrated environment, on the contrary, a formalized and rigorous approach based on cooperation is more appropriate.

Our study of standards for data exchange in an integrated environment is based on the PDES case. The technical and organizational problems that have been raised are not specific to PDES, but are general enough to be applicable to future standards for communication between independent systems and more generally to the design of information systems and technology development projects. Some important features of such standards are:

- These standards are to be designed in advance of their use. Consequently, they constitute an important shift from standards that are based on present systems and present technology that are trying to catch up with the development in information technology.
- They should be based on the concept of independence between the conceptual design and the physical implementation of the standard. Also, they should use formal methodologies and formal modeling languages.
- A formal approach for surfacing the different assumption in the design and the assumptions of different designers is crucial for the success of this project. For instance, an effort for the generation of a planning model such as the "Product Data Control Model" [Rockwell, 1987] that gives a high level and abstract view of the design may lead to an improtant bias. Also, it may mislead the evolution of a 'neutral format" unless a formal method for surfacing assumptions in the design can be specified.
- A formal methodology for partitioning the problem into manageable tasks must be done at the initial stages of the project.
- Cooperation among the different participants will dominate the political aspect of the process during the design stage of the standard and thus the management of the standard during this stage should be based on a cooperative framework.
- Education and learning is an important aspect of the process and management of learning should be an explicit aspect of the process. More specifically, well documenting the process is very important for its success.
- Checking the internal consistency and the external validity is likely to present significant difficulties during the process and further research in this field needs to be performed.

In the document, many key factors involved in the standards evolution process have been identified and analyzed. It is hoped that this discussion

should benefit individuals an organizations directly involved in the field of development of standards.

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